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ANALYSIS OF URBAN INFRASTRUCTURE FOR SUSTAINABLE MOBILITY THROUGH INSTRUMENTED BICYCLES FOR STUDENTS

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"A pair of wings, a different respiratory system, which enabled us to travel through space, would in no way help us, for if we visited Mars or Venus while keeping the same senses, they would clothe everything we could see in the same aspect as the things of the Earth. The only true voyage, the only bath in the Fountain of Youth, would be not to visit strange lands but to possess other eyes, to see the universe through the eyes of another, of a hundred others, to see the hundred universes that each of them sees, that each of them is; and this we do, with great artists; with artists like these we do really fly from star to star."

(Proust M. La Prisonnière, fifth volume of 'Remembrance of Things Past' , 1923)

In memory of my father

and dedicated to Olivia, without her constant faith and presence this work would not have been possible.

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Keywords

Cycle infrastructures, citizen science, healthy streets, urban health, GPS mapping, cyclists behaviors.

ABSTRACT

In Europe almost 80% of the continent's population lives in cities. It is estimated that by 2030 most regions in Europe which contain major cities will have even more inhabitants on 35–60% more than now. This process generates a consequent elevate human pressure on the natural environment, especially around large urban agglomerations, in which traditional components of the natural environmental, needed for the proper functioning of the ecosystem, and the human life within it, change drastically. Cities could be seen as an ecosystem, represented by the dominance of humans that re-distribute organisms and fluxes of energy and materials that leads to a distinct biogeochemistry, biotic diversity, and energy and material cycles. In these terms cities are the result of co-evolving human and natural systems, emerging from the interactions and feedback between humans, natural and technological system (including both physical infrastructures and digital ones). Among physical infrastructures, roads have a relevant role in building links between urban components and represent part of the basis on which it is founded the urban ecosystem itself. This thesis is focused on the research for a comprehensive model, framed in European urban health & wellbeing programme, aimed to evaluate the determinants of health in urban populations. The key concept for the researched model is to act on the transition from the concept of urban resilience as a passive process, to urban sustainability as a participative active process, oriented to ecological city development. In these terms the core field of the research is the urban cycling phenomena, viewed as an instrument to enhance sustainability and to outreach bottom up citizen participation on scientific data harvesting methodologies. Through bicycles, GPS and sensor kits, specially developed and produced by University of Bologna for this purpose, it has been possible to conduct on Bologna centre urban structure different direct observations that oriented the novelty of the research: the actual dynamic connection between transportation demand and offer, the categorization of university students cyclists, connection among environmental data awareness and level of cycling, and finally an early system to exploit environmental data to identify urban attributes able to impact on road air

quality and level of cycling. The categorization of university students' cyclist has been defined through GPS analysis and focused survey, that both permit to identify behavioural and technical variables and attitudes towards urban cycling. The statistic relationship between level of cycling, seen as number of bicycles passages per lane and pollutants level, has been investigated through an inverse regression model, defined and tested through SPSS software on the basis of the data harvest. All these dimensions establish the basis of the research project that represents a sort of dynamic mobility laboratory on two wheels, that permits to harvest and study detected parameters.

The work has been conducted by the author, in charge as mobility manager for the University of Bologna Multicampus, without correspondent funding.

Summary

Executive summary

This thesis is focused on the research for a comprehensive model, framed in European urban health & wellbeing programme, aimed to evaluate the determinants of health in urban populations. The key concept for the researched model is to act on the transition from the concept of urban resilience, as a passive process, to urban sustainability, as a participative active process, oriented to ecological city development. In these terms the core fields of action are the urban cycling phenomena, viewed as an instrument to enhance sustainability and to outreach bottom up citizen participation on scientific data harvesting methodologies.

The background in which the research case takes place is a middle size city, Bologna, a historical town with 380.000 inhabitant, that hosts one of the ancient universities in entire world, with 80,000 students and 6,000 academic and administrative staff. The relevant presence of the University has a strong impact on urban development towards sustainability and influenced both social economic and transportation order. Indeed, territorial presence of University extends from the very centre, integrated in core services and commercial activities, till peripherical isolated campus, in which traditional city-effect is still longer to come. The COVID-19 pandemic has given in Bologna, as well as in many others European cities, an impulse to individual sustainable mobility that even after each different series of lockdown phases, manifested a tendency of increasing attitude despite collective mobility. Among active sustainable mobility cycling represents a wide dimension, that students and university staff have chosen, manifesting attitudes toward bicycle, as main transportation mean in home-work commuting trips.

The research considers cycling an instrument with several functions: a point of observation of ecological behaviours, a catalyst for re-balancing urban ecosystems altered by the anthropogenic effects, a citizen science baseline to data harvesting on active mobility, an environmental dynamic laboratory in which it is possible to describe urban infrastructures though the lens of urbanism and policies attributes.

There are several aspects that indicate the novelty of the research:

- the comprehensive approach that permits to search for an innovative model able to dynamically connect demand and offer in transportation;
- the categorization of university students cyclists;
- the investigation on finding a possible connection among environmental data awareness and level of cycling;
- the exploitation of environmental data to identify urban attributes able to impact on air quality and pollution.

The dynamic adaption of Transportation Offer, in terms of infrastructures and path, to Demand, in terms of number of cyclists, has been analysed observing behavioural attitudes and habits on cycling of university student's category, while infrastructure levels have been studied in connection to urban and environmental elements. In digital era and Web 2.0 domains, this dynamic balance is granted by engaging people in almost real time useful data availability.

The categorization of university students cyclists has been defined through GPS analysis and focused survey, that both permit to identify behavioural and technical variables and attitudes towards urban cycling.

The statistic relationship between level of cycling, seen as number of bicycles passages per lane and pollutants level, has been investigated through an inverse regression model, defined and tested through SPSS software on the basis of the data harvest.

All these dimensions establish the basis of the Almabike project, a sort of dynamic mobility laboratory on two wheels, that permits to harvest and study detected parameters. Almabike is constituted by university branded and copyrighted bicycles, developed through a student challenge design call and then industrialized in all processes. These have been particularly challenging, due to the project holistic approach, focused on bicycle design and its production. 650 bicycles have been produced, in which 600 integrated by GPS tracker within the frame, and 50 integrated by environmental sensor kits. These sensors have been developed in cooperation with Fablab Barcelona, tested and produced with the goal to be installed aboard the bicycles and to be able to detect particles matters and environmental parameters in dynamic way during the trips. Following the assessment done on University of Bologna community about modal-share through the years and policy orientation on sustainable mobility, it has been possible to define that students present a solid attitude toward bicycles, at level that they could be categorized as a whole, while academic and administrative staff presents a manifest increased interested in use frequently bicycle as priority home-work mean of transport. By these results, the research has been divided in two parts: 600 bicycles have been given to students to analyse their cyclists category and 650 to academic and administrative staff to evaluate as environmental awareness may be related to passages of bikes per lanes and consequently be implement as an enhancing nudge instrument on cycling. These two parts indirectly represent aspects related respectively to Cycling transport Demand and Offer, and their equilibrium.

The project offers an innovative approach and a first observation point from which it is possible to develop new further scientific fields of investigation as well as decision support systems for local governance and urban policies on cycling and on exposure to pollutants during mobility processes.

The thesis is structured in Chapters that explore from literature reviews to project development, focusing mainly on the relationship between city, air quality, infrastructures and mobility behaviours.

In particular:

Chapter 1. Roads infrastructures and cycling in the passage from urban resilience to urban sustainability

explores the state of art of scientific literature in order to represent the path that link from hybrid urban ecosystem to specific topics regarding the categorization of cyclists and the environmental aspects related to cycle infrastructures.

Chapter 2. Policies on sustainable urban mobility at University of Bologna

illustrates the University of Bologna's policies on sustainable mobility, through the years from 2012 to 2020, comprehending: the core contents of the Mobility manager agreement between University of Bologna and the Municipality of Bologna, the Green Metric Rankings approach on transportation, and an innovative methodology on University Carbon Footprint calculation to evaluate also mobility projects impact. It is evident that interest towards active mobility, in particular cycling, is increased progressively through the years. Indeed, cycling became a dominant aspect for students and staff benefits and policies, able to orient significantly the habits changing toward ecological means and to reduce university impacts. Elements in which the research project is framed.

Chapter 3. Mobility behaviours in University of Bologna

illustrates the methodologies underlined the survey submitted to students and academic/administrative staff, with a specific focus on psychological models, related applications and results. The survey identified the modal share and in particular mobility attitude tendencies, i.e. students present a solid attitude to cycling, while employees manifested, specifically after COVID-19 impact, an increased interest towards bicycle as main home-work commuting transport mean. These two categories and their attitudes help to define the champion sample for the research.

Chapter 4. Almabike project storytelling

shows the entire project, exploring each single phase, from the origin of the students design challenge to the production, illustrating the development of any technical components, including sensor kit. A specific focus has been placed on sensors development, comprehending testing phases and novelty concerning the bike applications.

Chapter 5. Almabike research methodologies

describes materials and methods of the research, comprehending parameters as periods of observation, type of champion sampler and data analysis. A specific focus is given to data harvesting and data geo-processing.

Chapter 6. Almabike results

explains the novelty and the results on the stage of research concerning categorizing university students' cyclist. Chapter is completed with specific discussions.

Chapter 7. Almabike research on environmental data awareness

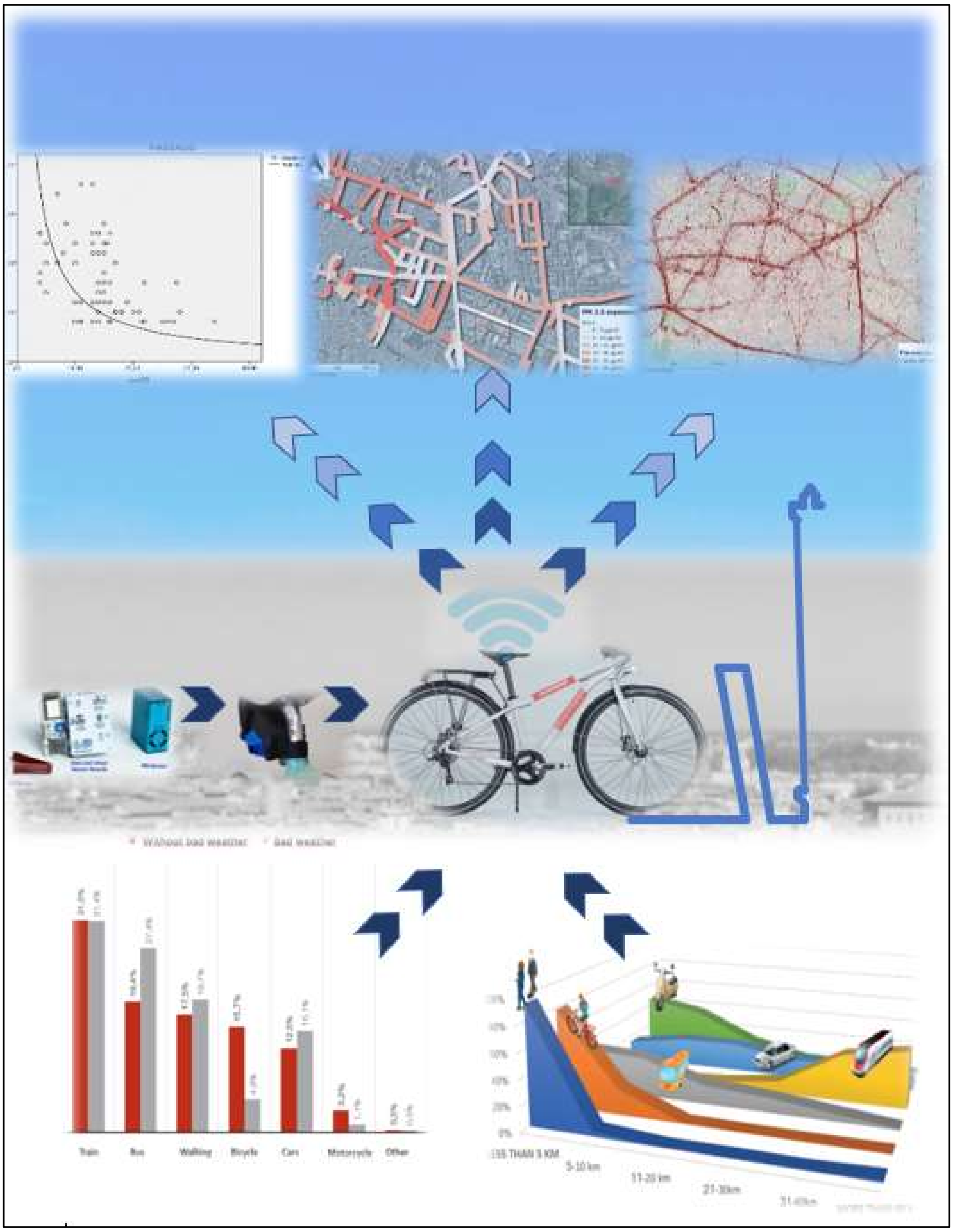
explains the novelty and the results on the stage of research concerning impact of environmental data awareness on cyclists at their passages on lanes. A final part presents an early evaluation of urban structured, policy and infrastructures items that may act on pollutants exposure to cyclists. Chapter completes with specific discussions.

Chapter 8. Conclusion

shows the two parts of the research as a whole, indicating the reached step of innovation and illustrating next-to-be development and exploitation of the overall project.

This work has been conducted by the author, in charge as mobility manager for the University of Bologna multicampus, without correspondent funding.

Below is illustrated a Graphical Abstract inspired by the Thesis work and a Flowchart of the overall research with chapters reference (in red square).



Graphical Abstract on overall Research overview

Flow Chart of the overall research with chapter reference

Chapter 1. Roads infrastructures and cycling in the passage from urban resilience to urban sustainability

1.1. Introduction

In Europe almost 80 % of the continent's population lives in cities (Antrop 2004). It is estimated that by 2030, most regions in Europe which contain major cities will have even more inhabitants on 35–60 % more than now (Melchiorri et al., 2018). This process generates a consequent elevate human pressure on the natural environment, especially around large urban agglomerations (Güneralp et al., 2013). With the expansion of the city, those traditional components of the natural environmental, necessary for the proper functioning of the ecosystem and the human life within it, change drastically. Urban fragments isolate and degrade any natural elements (Alberti, 2005), bringing reduction of native biodiversity and increase of invasive species (Grimm et al. 2008): loss of agriculture lands, pollution of streams, air and soils and modification of energy flows and nutrient cycles (McKinney, 2008).

During the past hundred years, advances in the scientific understanding of ecological systems have called for integrating humans into ecology (Alberti et al. 2003). In ecology, scholars no longer see ecosystems as closed, self-regulating entities that "mature" to reach equilibrium. Instead, they acknowledge that ecosystems have multiple equilibria and are open, dynamic, highly unpredictable, and subject to frequent disturbance (Pickett et al. 1992). But only in the last decade scholars of urban ecology started to expand their conceptual frameworks and methods of analysis to better represent socioecological interactions (Pickett et al. 2013). To study urban ecosystems, it is necessary to integrate multiple agents and boundaries and analyse processes at multiple scales, ranging from local to metropolitan, regional, and global: explicitly to link urban structures, biophysical processes, and human behaviours to ecosystem functions. Indeed, cities are ecosystem in which the difference from natural ecosystem is represented by the dominance of humans. By building structure and infrastructure in cities to support their needs, humans redistribute organisms and fluxes of energy and materials, that leads to a distinct biogeochemistry (Picket et al. 2001), biotic diversity, and energy and material cycles (Bai 2016). Alberti (2017) advanced that concept, assuming the hypothesis that cities are hybrid ecosystem, as the results of co-evolving human and natural systems, emerging from the interactions and feedback between humans, natural and technological system (including both physical infrastructures and digital ones), as illustrated in Fig.1.1.

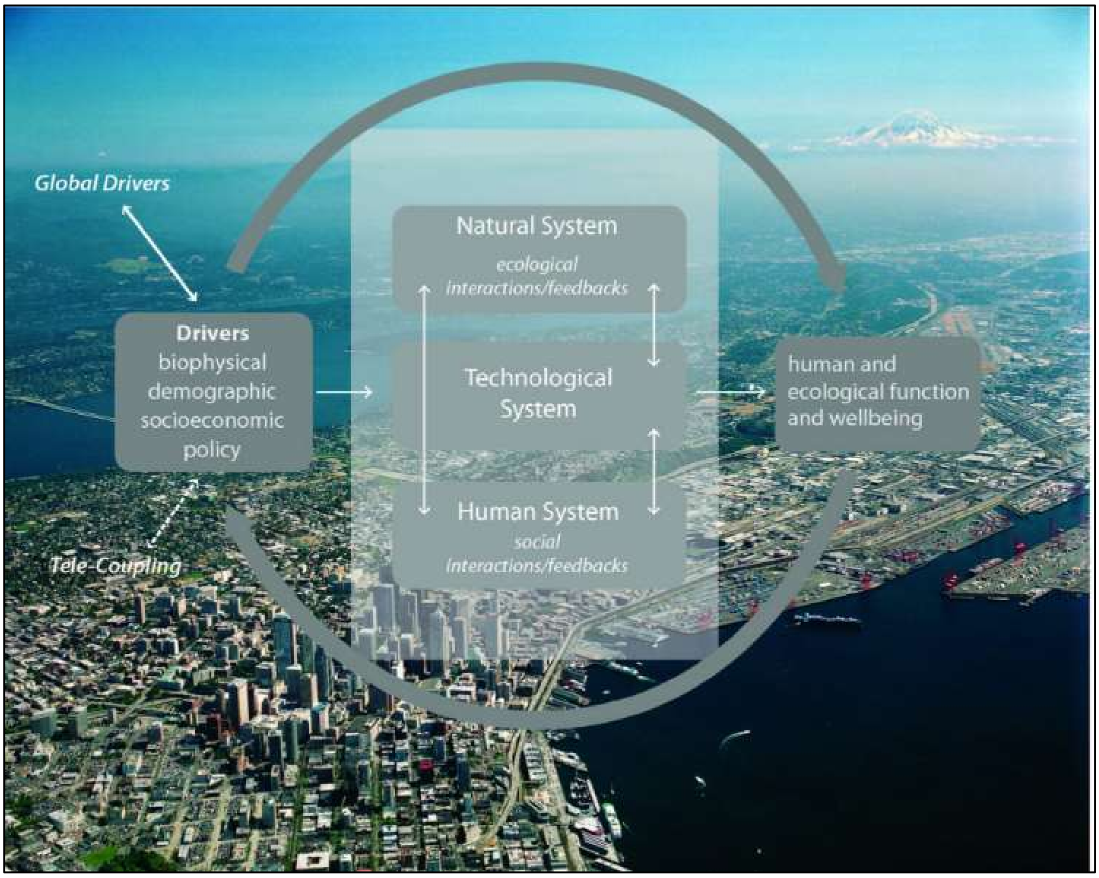
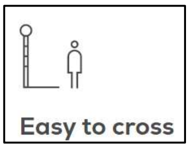


Figure 1.1 Human and Natural systems connections (Credit: The Urban Ecosystem, Alberti 2017, in Press).

In these terms, road infrastructures have a relevant role in building links between urban components (energies, environmental, biotic components) and represent part of the basis on which it is founded the urban ecosystem itself. Imaging urban systems as an integration of different overlapped layer, it means that each impacting effect produced by humans on urban hybrid ecosystem may be partially reduced, acting also on the road infrastructures layer. This action brings a new vision for the streets, depriving them of the traditional connection function and introducing a new approach, efficiently synthetized in the Healthy Street Approach promoted by Lucy Saunders (Healthy Street, 2020). The Healthy Streets Approach is a human-centred framework for embedding public health in transport, public realm and planning. The Conceptual vision is based on 10 evidence-based Healthy Streets Indicators, each describing an aspect of the human experience of being on streets. These ten indicators must be prioritised and balanced to improve social, economic and environmental sustainability through how streets are designed and managed. This approach can be applied to any streets, anywhere in the world. It builds improvements on existing conditions rather than seeking a fixed end goal. Taking this approach requires incremental changes in all aspects of the decision-making processes related to streets and transport. As illustrated in Figure 1.2, Healthy street model demonstrates that the streets should be welcoming places for everyone to walk, to spend time and engage with other people, in a circular integrated perspective. Through physical activities and social interactions, the road become vibrant places and helps to keep communities strong and alive. It's a buoy of "vital activation" of the city itself, that requires clear awareness of the environmental condition and social resources available in the expanded urban context. This vital activation takes step from the enhancing the following aspects:

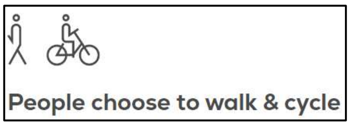


Streets need to be easy to cross for everyone. This is important because people prefer to be able to get where they want to go directly and quickly so if we make that difficult for them they will get frustrated and give up. This is called 'severance' and it has real impacts on our health.

To ensure our streets are inclusive of everyone and welcoming to walk and cycle in no matter the weather it is very relevant to pay attention to shade and shelter (trees, awnings, colonnades, etc.).

Regular opportunities to stop and rest are essential for some people to be able to use streets on foot or bicycle because they find travelling actively for longer distances a challenge. Seating is therefore essential for creating environments that are inclusive for everyone.

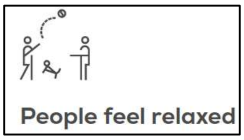
Noise from road traffic impacts on our health and wellbeing in many ways, it also makes streets stressful for people living and working on them as well as people walking and cycling on them. Reducing the noise from road traffic creates an environment in which people are willing to spend time and interact.



People will choose to walk and cycle if these are the most attractive options for them. This means making walking and cycling and public transport use more convenient, pleasant and appealing than private car use.

Motorised road transport can make people feel unsafe on foot or bicycle, especially if drivers are travelling too fast or not giving them enough space, time or attention. Managing how people drive so that people can feel safe walking and cycling is vital. People also need to feel safe from antisocial behaviour, unwanted attention, violence and intimidation. Street lighting and layout has also relevant components.

Street environments need to visually appealing to people walking and cycling, they need to provide reasons for people to use them – local shops and services, opportunities to interact with art, nature, other people.



The street environment can make feel anxious – if it is dirty and noisy, if it feels unsafe, if there is enough space. All of these factors are important for making our streets welcoming and attractive to walk, cycle and spend time in.

Air quality has an impact on the health of every person but it particularly impacts on some of the most vulnerable and disadvantaged people in the community – children and people who already have health problems. Reducing air pollution benefits all and helps to reduce unfair health inequalities.

Figure 1.2. Healthy Street indicators.

The conceptualization from Healthy Street model cannot leave aside the capacity of city to reduce external impacts, such as environmental or energies ones.

It has been consolidated that the primary effect of the presence of humans is unequivocally the rapid climate heating, unprecedent over centuries of thousand years, as stated by Intergovernmental Panel on Climate Change (IPCC) in its Sixth Assessment Report (IPCC, 2021). Further, experts reckon that even the Paris Agreement goal of limiting warming to well below 2°C and preferably 1.5°C does not represent a crucial safe condition, due to risk of self-perpetuating changes that consequently may lead to abrupt, irreversible, and dangerous impacts with serious implications for humanity.

As much as cities are becoming increasingly complex systems of social, economic and ecological factors (Liu et al., 2007), framed in an overall hybrid ecosystem, as much as they are very vulnerable when any of their subsystems are destroyed or fails to adapt to new challenges (Coaffee, 2010). Climate change becomes one of the uncertainty causes that may negatively acts on cities vulnerability, and it requests a different approach to urban planning that takes in account resilience factors. In 2009 the International Local Governments for Sustainability (ICLEI) in the "1st Global Forum on Urban Resilience and Adaptation" has been taken in accounts the concept of "Planning for Resilient Cities and Regions". That vision has been developed by the Association of Collegiate Schools of Planning (ACSP, US) and Association of European Schools of Planning (AESOP) in 2013 and consequently it has been also further recognized by urbanism academia in both the U.S. and the EU. But Urban Resilience has been frequently associated with Sustainability concept. Moreover, a deep difference has been found between them. Indeed Zhang, in his seminal study (Zhang et al., 2018) conducted through CiteSpace 4.0.R5 for finding co-citation networks and research clusters, has established the appropriate definitions. Urban Resilience has been pointed as the passive process of monitoring, facilitating, maintaining and recovering a virtual cycle between ecosystem services and human wellbeing through concerted effort under external influencing factors; while Urban Sustainability has been identified with the active process of synergetic integration and co-evolution between the subsystems making up a city without compromising the possibilities for development of surrounding areas and contributing by this means towards reducing the harmful effects of development on the biosphere. Understanding UR and US as two different concepts promotes a diversity of solutions to social-ecological problems. As illustrated in Figure 1.3 UR and US may be represented on a graphic in which Rational tendency is associated with formal urban planning process and Positive tendency to bottom-up hierarchy process, characterize by the dominance of a more subjective view. In contrary Irrational tendency is associated with unformal planning and Passive tendency with Top-down hierarchy and more objective.

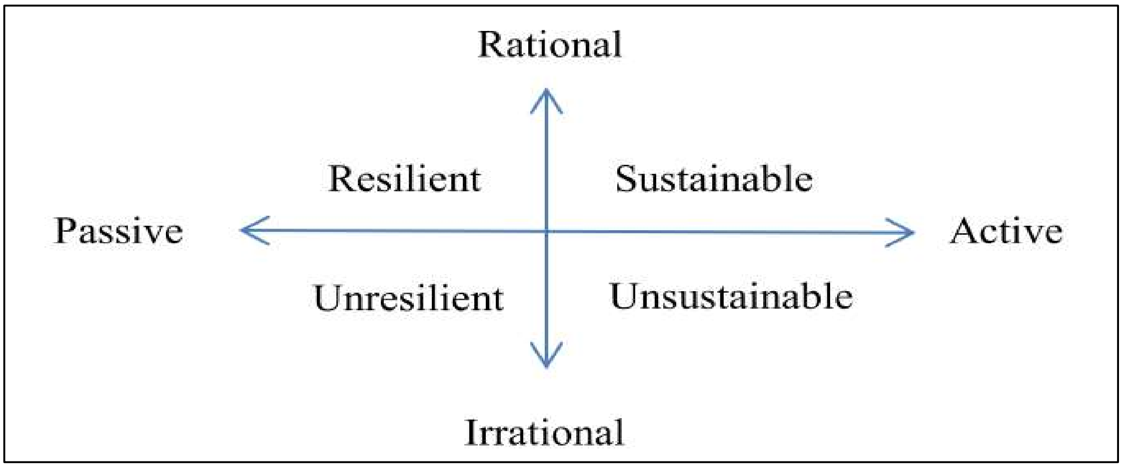


Figure 1.3. Difference between UR and US (Zhang et al.,2018).

It is possible to understand that the balance of urban hybrid ecosystem is driven by the need to pass from the Resilient quadrant to the Sustainable quadrant. Consequently given the positive Rational axis/formal urban planning, to lead this passage, it is necessary to introduce subjective measures and bottom-up processes. Urban planning results conditioned by this passage and manifests the need to adopt new paradigms to further transform cities (Wilkinson, 2012).

The requested paradigms should be founded on two main strategies:

- adopting policies able to enhance active sustainable mobility, able to balance any anthropogenic effect on an urban ecosystem;
- introduce participative and crowdsourcing methodologies, as key factor of a bottom-up planning process.

Each strategy is examined in paragraph 1.1. 2 and 1.1.3 on the basis of a literature review and placed the basis for the context in which the research illustrated in the present thesis has been conducted.

1.1.2 Enhancing urban cycling and increasing University cyclists strategy

The first urban strategy has been based on the recognition that cycling and walking are key factors to be urgently considered with the aim to define a new paradigm for urban hybrid ecosystem. According to a new publication, World Health Organization (WHO, 2022) stated that cycling and walking can help to reduce air pollution that claims more than half a million deaths every year. Evidences show that investments in policies that promote safe cycling and walking can play a crucial role in shaping health, mitigating climate change and improving the environment. A study based upon travel patterns, injuries, physical activity, fine particulate matter and GHG analysis, in the San Francisco Bay Area, demonstrates that daily cycling from 4 to 22 minutes decreased GHG from 14 to 33% (Maizlish et al., 2013). Shifting from motorized means of transport to cycling has positive effects on air pollution, traffic noise, congestion and space requirements, especially in dense urban areas (Bernardo and Bhat, 2014).

The relevance of cycling has been clearly represented during Covid19 pandemic, in which conditions cities have stopped the cars and enhanced cycling (Bereitschaft et al., 2020). The measures impacted on road infrastructures, with closures and new spaces recognized to pedestrians and cyclists, as it has been demonstrated in cities as Vienna, Milan, Boston, Oakland, Philadelphia and Minneapolis. These temporary road closures and other short-term measures are serving as testing grounds for changes that may eventually become permanent (Bliss, 2020). In parallel with increasing fuel costs, greater awareness of greenhouse gas emissions and increasing obesity levels, cycling is promoted as a health promoting and sustainable transport mode. Indeed, several sustainable benefits have been introduced by the advent of cycling i.e.: reduced pollutant emissions, increased active mobility of people, increased use of public spaces, reduction of urban and social degradation phenomena; increased local tourism (Pazzini et al., 2022).

A study aimed to quantify, in monetary terms, the health benefits associated with a shift from private cars and motorbikes to active mobility modes in Italy showed how the positive effect of increased physical activity of cycling outweighs the negative effect associated with higher air pollutant intake. The net benefit is much higher for walking than for bikes and e-bikes since pedestrians perform physical activity for longer times (even if they cover shorter distances) at lower ventilation rates. In case of cities with high levels of background air pollution (such as Milan and Turin), net health benefits from increased e-bike use might be very close to zero as damages from increased air pollutant intake and road risk injury might offset benefits from increased physical activity (Mela et al., 2022).

Bicycle as a mode of transportation, also can act on reducing the pressure on urban roads (Parkin et al. 2007), use of fuel (Kendrick et al.2011) and consequently air pollution (Koorey et al. 2010). Moreover, cyclist infrastructure's cost is considerably lower than other modes of transport (Gotschi 2011). For these reasons, local and regional transport authorities encourage people to use bicycle as one of the main modes of transportation (Kassim et al., 2020). Cycling is characterized by high travel-time reliability: this aspect is a strong point to promote cycling mobility, as the uncertainty of travel time is a vital factor for accessibility (Liao et al., 2017).

Consequently, in recent years, an increasing attention has been reserved by policy makers to cycling phenomena, in terms of Sustainable Urban Mobility Plans (SUMPs), road safety, and accessibility. In particular SUMP, as an integrated planning approach that addresses all modes and forms of transport in cities and their surrounding areas, contributes to the European climate and energy goals set by the EU. SUMPs challenge transport-related problems in a more sustainable way, in which cycling is a relevant part. Even if information on cycling is not specifically detailed in the SUMP guidelines, since 2011 ELTIS had counted more than 325 cycling projects in SUMPs (besides 325 pedestrian projects and 770 road projects). Cycling is framed in SUMPs within the concept of "Active sustainable mobility", together with walking, representing a solid alternative to private cars, introducing a lot of health and environmental benefits.

The Metropolitan City of Bologna SUMP, i.e. have a relevant aim in increasing cycling mobility, from 5% of 2016 to 14% in 2030. As illustrated in Figure 1.4, the main goal has been mainly identified in: transforming the bicycle into one of the main means of transport in the metropolitan area contributes to a more efficient, healthy, clean, safe and economic use of the urban space. Indeed, in the metropolitan area, half of the journeys are under 5 km and from these distances, easily cyclable, the challenge is to bring about an ultimate change in habits and mobility styles. Consequently, to stimulate the shift from steering wheel to handlebar, two integrated cycling networks will be complete by 2030. The first one, for daily journeys, will be extended the current 246 km to 944 km, mending and at the same time improving the existing routes. The 18 major radial and transverse routes will connect the main urban areas of the metropolitan city with each other and with Bologna. Moreover, it has only considered the opportunity to ensure a more convenient switch from bicycle to train, BRT (Bus Rapid Transit) or tram, thanks to the opening of the cycle park and cycle-stations in the new mobility hubs, as well as an extension of the services that allow you to bring bicycle on trains.

Figure 1.4. On cycling summary strategies – SUMP Metropolitan City of Bologna.

In order to enhance efficiently active sustainable mobility, cities require also a strong attention to safety and to cyclists behaviors, with the aim to identify strategies and actions to improve the cycling conditions (Pazzini et al., 2021). In general, strategies interest cycling infrastructure design and transportation demand soft measures, as appears in the shape of introducing innovative cycling services, adopting specific communication approaches, enhancing a different urban perception. In both issues there is a dominance by the topic of road safety. Considering that a total of 9,500 people was killed on urban roads in the EU in 2017, about 38% of all road deaths, cyclists and pedestrians together make up over half of all road deaths in urban areas and cyclists, accounting for 12% (EU Road Safety, 2017). However, cyclists represent one of the most vulnerable groups of road users (Pazzini et al., 2022).

On the other hand, city governances are struggling with the decisions of which kind of cycling infrastructure is better to invest on, with the aim of improving cycling, i.e., bike lanes on carriage or on separated paths, or bicycle crossings located in the middle of blocks, as argued by (Gashemi et al., 2022). In fact, as (Li et al., 2017) found in Toronto, Canada, some of the major factors that affect a cyclist route choice are distance, road type, and the presence of cycling facilities. Some other authors stressed the importance of infrastructures dedicated to cycling. In particular, it has been found that higher levels of bicycle infrastructure are positively and significantly correlated with higher rates of bicycle commuting (Dill et al., 2003), while the presence of facilities at roundabouts and junctions generally has not had a significant effect on perceived risk or acceptability of cycling (Parkin et al. 2007). The main implication is that the provision of facilities at a junction may have a counter-intuitive effect and suggest to potential cyclists that the junction is riskier than it might otherwise have been perceived to be. Bicycle facilities along trafficked routes contribute only a little to the moderation of perceived risk, but the major component of the reducing risk perception effect is for facilities that are off-road or adjacent to the road (Parkin et al., 2007).

In terms of urban policy, surveys conducted on several Canadian cities confirmed the importance of dedicated infrastructure and demonstrated that coordinating public transport with bicycling is a crucial factor in encouraging the use of both of these modes

(Purcher et al., 2005). Such integration can be achieved by provision of convenient and secure bike parking at both rail and bus stops, bike racks on all buses, and accommodation of bikes on all rail transit vehicles. Indeed, respondents to a survey at conducted at University of Maryland, College Park, mentioned the lack of bike lanes as the most important reason that keeps them far from bicycling (Akar et al., 2009). This finding reveals that a connected cycle network is the backbone of a successful bicycle program. In general, all surveys in both Canadian and American cities clearly indicate that more separate cycling facilities—bike paths and lanes—would most encourage people to cycle. Others studies has underlined the correlation between cycling and proximity to cycle path on separated carriages (Moudon et al., 2005).

It is interesting to underline how different perspectives stem from studies on individual basis. As pointed out by Antonakos (Antonakos et al., 1994), cyclists quantify the importance of environmental factors such as traffic volume and surface quality before choosing cycling routes. Age was positively correlated with preference for on-road facilities (striped bike lanes, wide curb lanes), with importance placed on surface quality, scenery, and bike safety education, but was negatively correlated with preference for bike paths separated from the roadway. Cycling experience was negatively correlated with preference for off-road facilities and concerns about safety, traffic, and terrain (Antonakos et al., 1994). A survey conducted by the College of Engineering at The University of Texas at Austin (Stinson et al., 2003) indicated that for commuter bicyclists, travel time is the most important factor in choosing a route. Presence of a bicycle facility (especially a bike lane or separate path), the level of automobile traffic, pavement or riding surface quality, and presence of a bicycle facility on a bridge are also very important determinants. An adaptative stated preference survey conducted in US (Tilhaun et al., 2007) demonstrated that cyclists prefer to increase the travel time with the aim to use designated bike-lanes. Their preferences are followed further by the absence of parking on the street and by taking a bike-lane facility off-road.

Another research has been focused on routing choices in which it has been revealed the attractiveness of the different types of infrastructures, taking into exams the effect of traffic volumes, topography and traffic control devices on route choices (Broach et al. 2011).This study relies on GPS data collection in Portland (US) with a participation primarily composed by regular cyclists and a sample of 44% females and 89% with age between 25 and 64. The study, based upon a Path-size Logit Model (PSL), demonstrates that cyclists prefer shorter routes, and find relevance of some factors on routing, as the preference for separated lane and lane with less exposure to high traffic level. Some interesting deduction concerned average trip distance (from 3.5 km to 3.7 km/h), average speed (from 16.1 km/h to 19 km/h).

1.1.3 Participative and crowdsourcing strategy

The second strategy that may leads to Urban Sustainability starts by the MIT-Senseable City Lab vision that breaks the traditional smart city paradigm on urban development. Figure 5 provides a picture of the main differences between smart and senseable city, for a better understanding of the different planes of work on which this thesis acts. The vision enrooted in the Senseable City Laboratory, a research initiative at the Massachusetts Institute of Technology, is focused on identifies how layers of networks and digital information blanket urban space, creating new approaches to the study of the built environment. Description of cities has changed and required different tools to measure and interpret, that are able to establish participative process and data-sharing. In this terms crowdsourcing has great potential to advance the field of infrastructure perception & preference research, as it enables the *in-situ* collection of real-time, location-based data. The research illustrated in this thesis considers the participative process as a relevant part of the data harvesting and collective contribution to innovation, able to act even on the personal plain of ecological consciousness. Participation process has been implemented by a crowdsourcing methodology, based on Volunteered Geographic Information (VGIS, as explained below) and pollutants detections, driven by a collective information sharing, as illustrated in next chapters.

Smart city	Senseable city
Technology as an aim	Technology as means
Technologies evolution	Citizens evolution
Replacing with Smart technology	Active partecipation to social life that needs technologies
To measure	To measure, to interpret, to act
Flexibile and mobile systems	Citizens who use enhanced technologies to change and to become flexibile and dynamic
Technology that makes city intelligent	Cities that become intelligent, due to Citizens' s new skills and their use of technologies

Figure 1.5. Comparison between Smart city and Senseable city (Marcatili et al., 2017).

The emergence of Web 2.0 and the release of public application programming interfaces (APIs) for online mapping tools and sites that enable uploading georeferenced content, together with the proliferation of mobile devices able to record the location, allowed non-expert users to quickly (See tal al., 2016) and easily display geographical information on shareable maps (Turner, 2006).

Consequently, spatial data collection and mapping has shifted radically from the exclusive domain of highly-trained experts, to increased engagement of the public. This novel set of techniques and tools that fall outside the scope of traditional Geographic Information Systems (GIS) as *neogeography* (Turner 2006). Aligning with the concept of neogeography, a wide range of new approaches and terms has been introduced in the literature to highlight the changes in the forms of spatial information that are available, and in the processes through which they are created and used (Elwood, 2008). The term volunteered geographic information (VGI) refers to intentionally created and shared data (Goodchild, 2007). In contrast, data collected without awareness or permission of data "producers" are often labelled as contributed geographic information (Harvey, 2013).

The semantic definition of crowdsourcing is "…*an online, distributed problem-solving and production model that leverages the collective intelligence of online communities (i.e. crowds) to serve specific organizational goals*" (Brabham, 2013), stressing that crowds are *given* the opportunity to contribute by organizations. Anyway, the intention of this research is to adopt a definition of crowdsourcing that extends beyond Brabham's definition and limit, including both VGI and CGI.

Crowdsourced geo-information has been used to visualize how people perceive and interact with landscapes and related infrastructure (Dunkel, 2015). This approach became part of a participation process for the reason that it can be used to mobilize public engagement in land use planning, infrastructural choice (Seeger, 2008), and advocate incentives to maintain and increase urban life quality, comprehending transportation choices, as routing? (Martinez Pastur et al., 2015).

The methodologies listed above indicate that crowdsourcing is increasingly harnessed to collect geographic information to support research on infrastructure perception and preference (IP&P). This type of geographic information is inherently subjective: it summarizes emotions, opinions, views and values of people in relation landscapes and/or ecosystems, often motivated by direct use (e.g. recreational activities), aesthetics, sense of place and belonging or existence values of biodiversity.

The volume and near real-time nature of crowdsourced geo-information enables inference of subtle spatial and temporal variations of the perception and preferences in landscapes and infrastructures. Measuring such spatial-temporal variations is a particularly challenging and time-consuming task to achieve with traditional methods, such as field observations or questionnaires.

An interesting approach has been proposed a novel geospatial mapping service, based on OpenStreetMap, which has been designed and developed in order to provide personalized path to users with special needs. In order to provide a complete urban mobility service to citizens the study has considered the following design issues: real time data about public means of transport availability, density of data (coming from official open data and from sensing and crowdsourcing activities), trustworthiness of crowdsourced and sensed data, and personalization of the proposed routes (taking into account accessibility of the urban environment and of public means of transports) according to user's preferences and needs. The resulting service supports citizens with reduced mobility (users with disabilities and/or elderly people) suggesting urban paths accessible to them and providing information related to travelling time, which are tailored to their abilities to move and to the bus arrival time (Mirri et al., 2014).

1.2 Almabike Research Project

This thesis regards a case study developed at the University of Bologna and concerns University student cyclists and staff behaviour and related choices on cycling in terms of infrastructures and environmental condition. The project Almabike, illustrated in detail in next chapters, regards a holistic approach that takes shapes from an initial student-bicycle design and production till the research applications. In particular, as suggested in the paragraph 1.1 on the basis of two main fields of urban strategy aimed to orient from Urban Resilience (UR) to Urban Sustainability (US), the research has been consequently oriented to investigate two different issues:

A. Categorizing University Students Cyclists and analysis on their urban cycling behaviour.
B. Experimentation effect of crowdsourced air quality detection and statistical evaluation of the awareness effect on cycling.

Each of these two issues has been associated to the university policies, as mentioned in chapter 1, in the field of Sustainable Campuses urban mobility plan.

To advocate the novelty of the research a literature analysis has been conducted on both two topics.

1.2.1 Literature analysis on University cycling

Categorizing the types of cyclists is a relevant topic among this kind of behavioural analysis, in which it has underlined the need of finding general and common approach and key factors acting on cycling by homogeneous groups. About this point Kroesen (2014) defined the analysis on two main categories: bicycle commuting and non-work cycling, while an analysis conducted in Canada revealed four distinct cyclist types: dedicated cyclists, path-using cyclists, fair weather utilitarians, and 10 leisure cyclists. A survey conducted at the University of Cagliari permitted to analyses the way in which the bike is perceived by “utilitarian bikers”, “hedonic bikers” and “non-cyclists” categories (Sottile et al., 2020). More recently, Poliziani (2021) define three users’ categories using a dataset made up of GPS traces: risky and hasty, sly and informed and inexperienced and inefficient. In literature, findings in cyclist categories have been generally based on behavioural factors as social, attitudinal, experiences, safety perception and similar.

Universities offer a cross-section of the population from different socio-economic backgrounds and ages, and consequently they generate irregular schedules and constant movement of people throughout the day, with also a risk of social exclusion related to the urban position of the campuses (Kenyon et al., 2002). This is even more noticeable in university campuses located in suburban settings in which daily commuting of the university population requires longer distances travelled, and the predominance of private car use over non-motorized means of transport (Guash et al., 2003). Consequently, various transport policies and plans have been adopted internationally to improve the overall quality of mobility around university campuses, in the terms of applied SUMP into a local urban dimension. To orient SUMP design and to measure effect of sustainability actions, in recent years an increasing number of universities around the world have begun to make data inventories and analysis based upon greenhouse gas emissions (GHG) produced by travel and home-work commuting. Some studies evaluate the variability from 8% (Clabeux et al., 2020) to 51% (Mendoza-Flores et al., 2019) of these transportation impacts.

Universities frequently import to their campuses the traditional SUMPs approach, defined by Eltis Guideline (Eltis, 2021) in which the private cars reduction plays a relevant role in parallel with increase active sustainable mobilities. It is not uncommon that University Students mobility shapes the overall transportation requirements of the hosting city. A study conducted in several campuses in Vietnam showed that students are more likely to travel by walking or cycling rather than by riding a motorcycle if most of roads to school are not lanes separated for four-wheeled and two-wheeled vehicles, and that an effective urban strategy to encourage the use of active modes by university students might be to provide more student apartments directly on or near the university campuses (Nguyen et al., 2018).

Students represents the youngest portion of the university population and in general they are less oriented to possess a car, committed to live near the campuses. They manifest the tendency to travel by public transport and active modes. In the case of University of Alabama, i.e., indicate that urban spaces within one mile from the campus site, have the highest level of active mobility of all the entire territory (Lundberg et al., 2014).

It is relevant the finding that the modal shift of students and staff may be also strongly influenced by University policies, such as park pricing or congestion charge. A study on the America University of Beirut demonstrates that increasing parking fees and decreasing bus travel time through the provision of shuttle services or taxi sharing could be promising strategies for mode switching from car to public transport for students (Danaf et al., 2014).

It has been demonstrated that students have also a more structured environmentally conscious and open-minded to new ideas, including in the transport domain (Gurrutxaga et al., 2017). Consequently, the role of cycling is highly impacting in student mobilities in urban area.

Even if there is a current lack in literature on specifically focused studies on the category of university student cyclists, some interesting findings identify the absence of dedicated infrastructure (e.g., cyclepaths safe bike lanes and bike stations (Lundberg et al., 2017) as major barriers preventing students from commuting by bicycle. Other critical factors for cycling are travel distance and travel time. For example, Wang (2015) found that proximity to bicycle infrastructure and the distance from campus were important factors in bicycling to the Ohio State University, USA. In the case of the Autonomous University of Barcelona, Spain, two distinct researches (Guasch et al., 2003 and Miralles-Guash et al., 2010) showed that long travel distances were the second main barrier preventing students to cycle to the university, while the first was more simply not having a bicycle. This second issue is relevant by the fact that university students, in particular at early stages of their carriers (first months i.e.), suffer the lack of adequate knowledge of the city urban structures and spatial distribution of services and consequently they are not fully able to move with independent and owned vehicles. It is easy to see a comparison between new freshmen scholarships and middle term tourists which kind of sojourn does not permit a complete grade of awareness of not collective transportation solutions. Further somewhere it is frequent that bicycles stealing act strongly disincentive of bike use itself. In these terms campuses policies able to orient students, in particular freshmen, towards bike sharing, may have an overall positive effect on enhancing cycling.

Purpose of the research illustrated in this thesis is to offer an analysis on University cycling, in terms of student categorization, students' behaviour and impact of the environmental awareness on home-work commuting.
In next chapters the relationship between environmental issues and university has been deepened within the case study of University of Bologna. The scientific interest lies also on the framework of University of Bologna itself, a large University whose complexity permits to create an overall perspective on this category.

1.2.2 Literature analysis on environmental dynamic data harvesting

The second issue of the research illustrated in the present thesis has been focused on crowdsourcing methodologies to harvest environmental data (pollutants as PM1, PM10 and PM2.5 as mentioned in next chapters), collected through bicycles, and visualized online to evaluate the impact of environmental awareness on home-work commuting with bicycles.

The literature on similar case of data harvesting through mobile bicycle-based sensors, has been mainly focused on the quality of environmental data, their urban assessment and the evaluation of cyclists' level of exposure to air pollutants. Indeed, air pollution exposure is particularly high for travellers because of proximity to mobile sources of pollution (Kaur, et al. 2007), and air quality is a source of concern for urban bicyclists (Badland et al., 2009).

Main factors that influence the cyclist's exposure have been identified in: time of day, that incorporates in itself some influencing effects as local weather and diurnal traffic patterns (Hatzopoulou et al., 2013), trips location in which have a strong impact the separation from motor vehicle traffic (Hertel et al., 2008).

A particulate air pollution measurement campaign in Minneapolis, on concentrations of Particle Numbers, Black Carbon, and PM2.5 as well as particle size along 3 routes (∼100 km total) repeatedly during morning and afternoon rush-hours, has been oriented to explore patterns of exposure while cycling (Hankey et al., 2015). The research, defined on 34 days between August 14 and October 16 2012, demonstrated that the share of on-bicycle exposure attributable to near-traffic emissions has been about 50% for PN and BC, and 25% for PM2.5.

A study conducted un Stuttgart, Germany, explored a data harvesting methodology, to be used as an addition to stationary monitoring stations, based on a mobile measurement platform with a bicycle. Different compact measuring devices were selected and installed on the bicycle for mobile measurements along a designated route. The measured pollutants included Particulate Matter (PM), Ultrafine Particles (UFP), Black Carbon (BC), nitrogen oxides (NO, NO2 and NOX) and ozone (O3). Meteorological parameters such as air temperature, relative humidity, wind speed, wind direction, solar radiation and air pressure were also measured. These measured parameters were allocated to the location using a GPS device and carried out during February 2018. The results showed a very high spatial variability and influence of factors such as local traffic and meteorological condition on pollutant concentration. The research demonstrated also that mobile detection offers a highly adaptive and flexible method (Samad et al., 2021).

A study conducted on 32 volunteers in Dublin, has investigated the pollution exposure of cyclists in comparison with several modes of transportation (public transportation, cars, walking, etc.), finding that while cyclists' exposure concentration was not always the highest, their pollutant inhalation doses were the greatest (Nyhan et al., 2014). A similar research on three European cities, Helsinki in Finland, Rotterdam in the Netherlands and Thessaloniki in Greece, measured the personal exposure to various-sized particulates, soot, and noise during commuting by bicycle, bus and car. The dataset configured on a total number of one-way trips yielding data on any of the measured parameters were 84, 72, 94 and 69 for bicycle, bus, closed-window car and open-window car modes, respectively. The highest mean PM2.5 (85 µg/m3), PM10 (131 µg/m3), black carbon (10.9 µg/m3) and noise (75 dBA) levels were recorded on the bus, bus (again), open-window car and bicycle modes, respectively, all in Thessaloniki, PM and soot concentrations were generally higher during biking and taking a bus than during a drive in a car with closed windows. The finding showed how active- and public-transport commuters are often at risk of higher air pollution and noise exposure than private car users (Okokon et al., 2017), while in 2001 a study demonstrated that cyclists sometimes have lower exposure concentrations than motorized modes, especially when they use facilities that are separated from traffic (Adams et al., 2001).

A recent application to assess the exposure in real time of cyclists to particulate matter (PM) and black carbon (BC), was carried out on typical bike lanes in Xi'an, the largest city in north western China, on a sampling routes (6.3 km) chosen to represent a typical lane used by cyclists in urban area, which includes multiple types of bike lanes, as illustrated in Figure 6 and 7. The inhalation dose as well as the deposition and distribution of different sizes of PM and BC in cyclists' respiratory systems, were quantified using a multiple-path particle dosimetry model. A statistical analysis has been conducted, through a linear regression mode, to explore the impact of several factors as temporal exposure and spatial variability along the sampled routes. Their exposure to $PM_{2.5}$ and BC showed specific urban hotspots, identified in intersections, temporary parking sites for vehicles, and diesel vehicles (Qui et al., 2022).

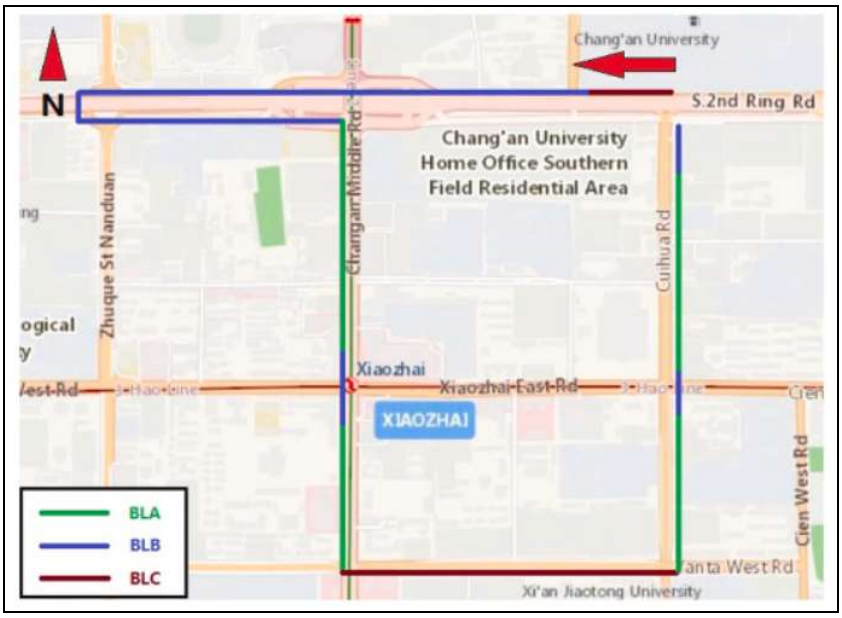


Figure 6. Experimental site and cycling route sampled in Xi'an, China. (Qui et al., 2022).

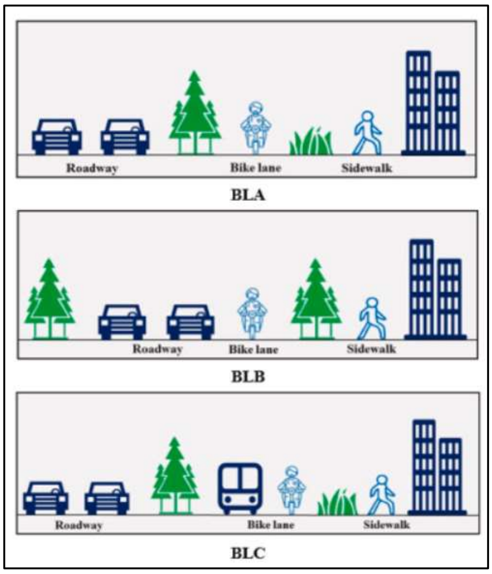


Figure 7. Schematics of the three types of bike lanes monitored for cyclists' pollution exposure (Qui et al., 2022).

Only few studies have looked at bicyclist-specific factors that could influence exposure, such as lateral position in the road, proximity to exhaust pipes, breathing height, and the ability to 'dodge between' vehicles (Kaur et al., 2007). The infrastructural impact of pollutants exposure has been evaluated and deepened in urban planning perspective, in two interesting case study in the city of Riverside, California. In particular the method has been aimed to integrate exposure to traffic-related air pollution in the bicycle route planning process. The method first applied a streamlined process for estimating the level of near-road air pollution concentration, then a bicycle route planning tool has been developed which allows planners and engineers to compare the exposure of bicyclists to traffic-related air pollution among different bicycle route options. Through the case studies, it has been showed as considering exposure to traffic-related air pollution can change the results of bicycle route planning (Luo et al., 2020).

In literature is present a current lack concerning effect of awareness of urban pollutions information on cyclists behaviour. The novelty of this part of the research is to investigate the initial presence of statistical correlations between bicycles passages on lanes and level of pollutants, under the specified circumstance that cyclists are update on a daily basis of the detected air qualities in routes within their home-work commuting. The aim, the methodology and the results of this part of the research is described in next chapter.

Chapter 2. Policies on sustainable urban mobility at University of Bologna

2.1. Introduction

The Alma Mater Studiorum - University of Bologna is an Italian public university that was formally established in 1088. The “Scuola of Bologna” arose spontaneously through the initiative of some students, gathered in primordial associative forms, who dictated the aims of teaching and controlled its correct implementation. In XI and XII centuries, it has been reported that *magistri* were paid directly by students, who often welcomed the latter into their homes, establishing almost family relationships with them. Around the innovative Schools of Law, students soon gathered in mutual assistance associations, which over time were structured according to their places of origin (*Nationes)* and finally aggregated into prestigious supra-regional corporations called universitates. Since then, lawyers and artists have enjoyed an unparalleled social and political reputation: indispensable to a Europe that was being born and that needed solid legal and cultural foundations.

This community-oriented approach remained alive through the centuries and currently University of Bologna is developed on several campuses located in Bologna, Cesena, Forlì, Ravenna, and Rimini, as illustrated in Figures 2.1 and 2.2. The university is organized into 5 schools, 32 departments (of which, however, only 17 are grouped into the 5 schools), and 232 study courses covering 16 subject areas. It includes centers and libraries and offers study facilities indicated in the Social Responsibility Report (University of Bologna, 2021). A general overview of University of Bologna has been reported in Figure 2.3.

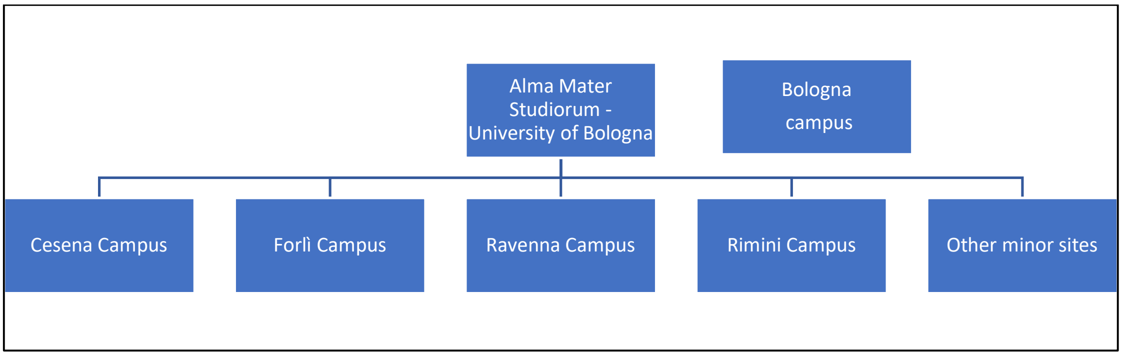


Figure 2.1. Organizational boundaries.

Figure 2.2. Territorial distribution.

With 85,000 enrolled students, 6,000 employed as academic and administrative staff, 232 courses of study (a.y. 2020/2021), of which 93 are Bachelor's degree and 125 Master's degree courses, University of Bologna plays an important role due to its huge size in terms of environmental urban impact.

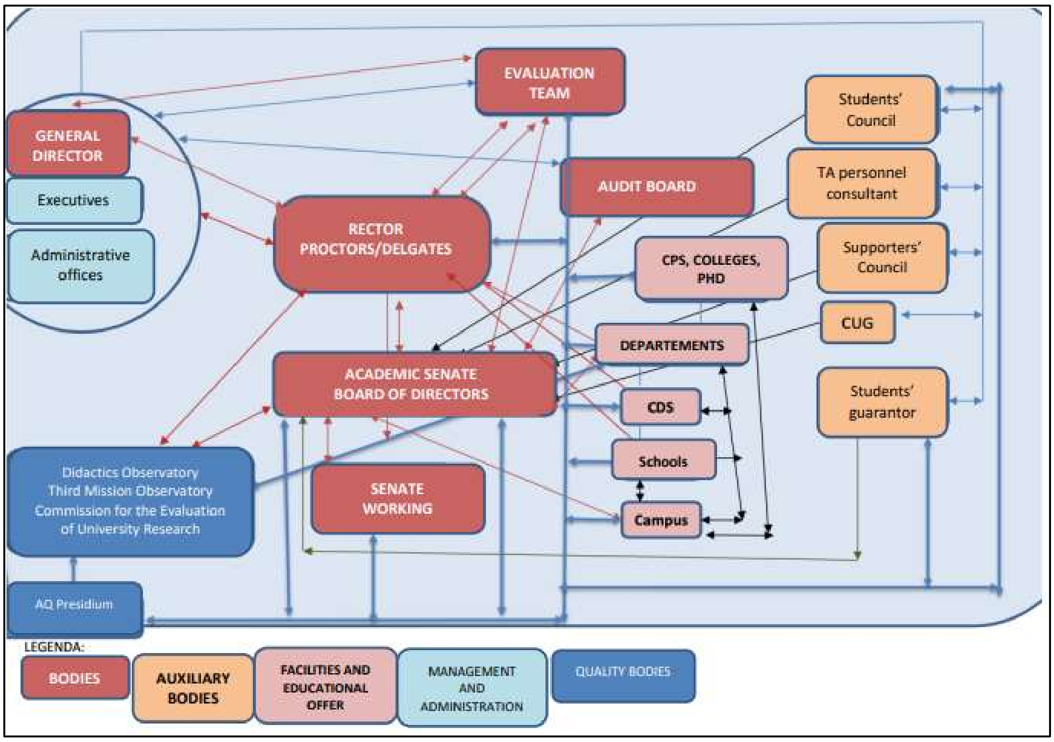


Figure 2.3. University of Bologna overview.

2.2 University Policies on sustainable mobility

Since 2006 University of Bologna has placed a particular interest on sustainable mobility actions. Exploiting the normative background created by the Environmental Ministerial Decree "Ronchi" 27th march 1998, that established formally the figure of Mobility management, University of Bologna has applied measures aimed to enhance public transportation use by university staff, comprehending both academics and administrative employees.

Mobility management, often called 'smart mobility', is a cost-effective instrument for bringing mobility and transport more in line with sustainability. It is complementary to technology and infrastructure measures and it is the additional key needed to achieve sustainable mobility on the local, national and European levels. It has been defined in many different ways and is also changing over time, but recently EPOMM endorsed the definition as developed by the European MAX-project in terms of “*a concept to promote sustainable transport and manage the demand for car use by changing travellers’ attitudes and behaviour”* (EPOMM, 2022). At the core of Mobility Management are "soft" measures like information and communication, organising services and coordinating activities of different partners. “Soft” measures most often enhance the effectiveness of "hard" measures within urban transport (e.g., new tram lines, new roads and new bike lanes). Mobility Management measures (in comparison to "hard" measures) do not necessarily require large financial investments and may have a high benefit-cost ratio.

It is relevant to underline that the role of mobility management has been early promoted by EPOMM, the European Platform on Mobility Management, founded by a number of committed Member States. EPOMM’s aim is to function as the knowledge hub for mobility management and to disseminate the concept in order that it becomes integrated in Sustainable Urban Mobility Plans (SUMPs), as well as in national and European mobility strategies. EPOMM fulfils this function in the following four ways. First, EPOMM facilitates the exchange of knowledge and experiences among policymakers, stakeholders, experts and practitioners. EPOMM is a knowledge network of people and countries that meet regularly to exchange their experiences in mobility management. The highlight of the year is the annual European Conference on Mobility Management (ECOMM). This exchange of knowledge is further supported by a monthly newsletter. Second, EPOMM has developed a broad range of tools:

- the European Modal Split Database (TEMS) provides the modal split data for more than 350 cities across Europe. Even though calculation methods (urban scales, journey types, etc.) are not the same from one country or one city to another, it allows comparisons as a first approach, which is better than the previous lack of data;
- the EPOMM evaluation tool MaxEva facilitates the evaluation of mobility management projects, compiling data on an ever-growing number of MM projects throughout Europe;.

- two policy evaluation tools are aimed at supporting the evaluation processes (MaxQ and MaxSumo) – the MaxSumo method can be used on MaxEva;
- several web-based policy development tools (MaxExplorer, MaxLupo and MaxSem) can be used to develop mobility management measures;
- Mobility management monitors per country and for the EU, which provide insights into developments in mobility management.

Third, EPOMM facilitates policy transfers among countries, cities and regions, for which standardised policy and best practice transfer processes have been developed. Moreover, EPOMM acts as a training agent, helping trainers find the right format and reach the right audience. Fourth, and finally, EPOMM puts emphasis on raising awareness amongst national and European stakeholders that mobility management is not just a local or a regional issue, but should be part of the agenda of national and EU policies. EPOMM's aim is that national and EU decision makers undertake initiatives to stimulate and support mobility management (EPOMM, 2013)

As mentioned above, in Italy the heritage of Mobility Management has been founded by Ministerial Decree "Ronchi" 27th march 1998, that defines the professional role of mobility manager as a heading figure in private and public organizations and companies accountable in the field of transportation and aimed to reduce the use of individual private means of transport and to define better organizing timetables to limit traffic congestion. The Decree also defined that any organizations with at least 300 employers, should edit and approve the Home-work commuter plan any years and share with local governance. The annual plan was intended as a sort of tactical document that indicates the employee modal-share, goals and main actions

More recently, during COVID-19 pandemic, the Mobility manager figure has been revisited with a new set of normative with the goal to relaunch in more formal and practice terms its activities. The normative sources are: Interministerial Decree n. 179 of 12 May 2021 (art. 3 paragraph 5), Decree of the Ministry of Ecological Transition of 16 September 2022, which amends the Decree of 12 May 2021 containing "Implementation methods of the provisions relating to the figure of the Mobility Manager". The new definition of Mobility manager is stated as: "a figure specialized in managing the demand for mobility and promoting sustainable mobility in the context of home-work travel for employees”. It is interesting to focus on the change of semantic paradigm and the attention specifically given to the transportation demand concept. The normative also reduces the limit from 300 to 100 employers, on the basis of which the organizations have to appoint the mobility manager and edit the Commuter Plan. Guide Lines to edit the Commuter Plan has been published by Decree n. 208 4th august 2021, further abrogated. Anyway, the main contents and structures for the Plan has been established and currently request by the local government (municipalities and Metropolitan city authorities).

University of Bologna started in 2006 with a single action aimed to enhance public transport by his employers (both academic and administrative) based upon subsided annual tickets. Initially the annual ticket subsided price was defined by the convergence of 10% of contribution by University of Bologna and 10% of contribution by the Local Public Transport company (ATC SpA, now TPER), creating an overall price reduction of 20%.

Progressively, through the years, the interest of University governance towards personnel benefit measures, comprehending mobility subsided solutions, is strongly increased, bringing different approaches to this kind of action and outreaching yearly more new public transport users. In paragraph 2.2 some policies through the years has been examined. In particular the more relevance goals has been the modal shift from private cars to public transport and the improvement of conditions able to enhance home-work commuting by bicycles, with a specific attention for university students.

The University of Bologna mobility measures have been framed in European Sustainable Development Goals (SDGs) 11 – Sustainable City and Community, and each of them adopt the European Transportation Green deal approach, with particular focus on topic 3- Resilient Mobility, in regards to Creating a mobility system that is fair and just for all (European Commission, 2020), as illustrated in Figure 2.4.

Figure 2.4. European Transportation Green deal- topic 3.

2.2.1 Measures and practices towards an ecological mobility on campuses

The early approach to sustainable transportation policies by University of Bologna date back to 2006 with the first application of public transport (both train and buses) subsided ticket for employers. The initiative interests initially about 600 employers. In 2007 the ticket purchase process has been digitalized and simplified, so that it has been possible to increase the number of users, rising stable to 1,000 workers.

Scenario has changed abruptly in 2012 with the introduction of a strong price reduction for administrative employers which low socio-economic condition required a specific attention. Further, close to these traditional public transportation policies, progressively has been associated goals and measure interesting other fields, as institutional fleet management and cycling. The chronology for university policies has been synthetized in annual Social Responsibility Balance. In synthesis, since 2012 University of Bologna has decided to invest increasingly in Mobility as a service (MAAS) field, to provide its employees with increasingly convenient forms of facilitation and, on the other hand, to achieve the numerous social and environmental benefits associated, as: reduction of air and noise pollution; reduction of the number of accidents; reduction of road congestion; reduction of transport times; synergy with local authorities in the implementation of common strategies for valorising the territory. Main fields of interest were defined in: policies oriented to enhance public transport, institutional car fleet management development and pro-cycling measures. The progressive investment in public transport permitted to release subsided tickets with a discount price about 50% for academic staff and a strong reduced price, variable from 50 or 100 euros, depending on the nature of the ticket (single urban area or integrated one), for administrative staff. From 2012, that registered about 1,700 public transport (TPER) annual tickets for urban, suburban and local railway, 455 for annual train tickets, and 250 integrated train + bus urban tickets, it has been possible to reach, in 2017 has been totally distributed 2,581 tickets, in which 1,947 as TPER (splitted 1,347 urban tickets, 252 suburban, 321 integrated tickets + bus) and 565 train tickets. During this period, it has been observed an average distance for train transport about 90 km. Otherwise for the local transport company START on Campuses of Romagna, in municipalities of Cesena, Forlì, Ravenna ed Rimini, it has been registered a constant value of 70 tickets. In 2018, with the aim to overall reduce the environmental impact of university activities, the University of Bologna has defined the holistic project **Sustainable Multicampus** that represents a framework in which insert each sustainable measure, comprehending mobility measures. Within Sustainable Multicampus, the subsided ticket has been extended to students, with 8,604 tickets in 2018 and more than 13,000 in 2020, including tickets for first and second degree and PhD students. Employees instead remained constant, compared to 2017.

In the field of car fleet management it has been developed a project that permit to dismiss more than 100 vehicles in property, substituted by a car shared institutional fleet, based upon rented cars. The project has been structured through a digital booking system that offer the opportunity to book vehicles and have interfaces with an automatic key released system. Vehicles are selected among ecological vehicles only, full electric or hybrid for long distance trips. From 2012 to 2020 it has been possible to reach about 50 vehicles, comprehending different models, including: Citroen C0, Renault Kangoo, Tesla Model S, BMW i3, Nissan Leaf, etc. In 2020 some fast charger systems have been installed in Bologna and campuses.

Given the increase interested on bikes, it has been extended the overall number of parking lots for bicycles, with more than 200 lots, defined an agreement with Cycle station for repairs and secure parking, and also developed new cycle-paths to/from peripherical campuses, like on the Center-CAAB direction, Center-Terracini, Belmeloro-Andreatta, and towards Navile Campuses. These infrastructures have been planned and designed in partnership between University and Municipality, under the frame specific agreements.

Finally, it is interesting to underline how public transport policy represents a driven approach. During the observation period, from 2012 to 2020, a stationary condition has been reached, so it will be difficult to increase further the level of tickets provided. In addition, smart working measures have reduced the daily needs of commuting. Indeed, a paradigmatic change has been registered among years before 2018, in which the adopted solutions has been configured as a convergence of two contribution (by University and by Public transport), and after years 2018-2019, in which a new methodology has been structured on a fixed *forfeit* contribution by the University necessary to apply an overall price basic reduction. In addition to the new methodology, a further investment has been provided to offer a lowest subsided price to students and administrative.

It is also relevant to consider that the investment during the years increased, reaching in 2019 and 2021 about 1,900,000 €.

The fact that both measures permitted to reach the *plateau* of public transport users required to University a new strategy aimed to increase the sustainable mobility. The Almabike research intends to investigate student behaviour and external factors able to act on ecological attitudes of university community, and offers a scientific approach to select criteria for cycling improving in urban area.

2.2.2 Mobility management three-years agreement

Municipality of Bologna offered the opportunity to main public stakeholders in Metropolitan City of Bologna, as University of Bologna, to sign a three years Mobility management Agreements. This tactical instrument covered the multiyear scenario in which, in each year, the Commuting Plan is realised. The three years Mobility management Agreements has been structured by goals related to soft measures, and their state of implementation, as illustrated in Table 2.1, for the specific 2021-2024 Agreement.

Goals	Implementation
public transport	**2017-2020**: On the basis of number of tickets provided, mentioned in Table 1, with an average value of 7,000 subsided tickets per years. **2021-2024**: main measure is the extension of subsided tickets to PhD students, first and second master degree, and Medicine Specializations students. Another measure is represented by the application of a common fixed price for both urban and suburban areas.
train transport	**2017-2020**: trend is stable with average 600 annual tickets. Details in Table 1. **2021-2024**: main goals are: the extension to students of subsided ticket for train transport system and to introduction of online purchasing procedures.
Car fleet and micro mobility	**2017-2020**: the project previously presented in Table 1, offers a new fleet management approach with 50 ecological (full electric and hybrid) rent vehicles, comprehending also van (N1 category), towards a sharing models between different departments. **2021-2024**: in addition to existing car fleet, the main goals are to introduce public car sharing usage for institutional mobility and micro-mobility device. In parallel a minor number of vehicles will be substituted the 2020 consistency.
Reduction of the need of transport	**2017-2020**: during the early months of 2020, the Administration of the University of Bologna launched an analysis aimed to investigate the opportunity for smart working first policies' introduction, in response to the evolution of normative context. Further, abruptly impact of COVID-19 has forced administration to start up a wide spread emergency smart working. **2021-2024**: Following mandatory normative, the University has introduced Smart Working method on an experimental basis in some

	departments and in some management areas of the University with the aim of arriving at a full adoption of Smart working regulation, valid for the entire, University starting from the early 2022.
Improving sustainable active mobility commuting	**2017-2020**: overall more than 200 parking lots for bicycles have been installed and a park facility has been available through the agreement with Dynamo cycle-station. **2021-2024**: the increasing interest for cycling regards mainly the goals to establish a network of cycles stations and secure bike parking facilities in proximity of main campuses, comprehending also peripherical ones.
Pro-cycling campuses	**2017-2020**: in 2021 Almabike project has been activated though more than 300 bicycles given to students. **2021-2024**: 50 electric bicycles will be provided to Department to increase active mobility. A cooperation with Municipality of Bologna will be defined with the aim to design new cycle-path in connection of peripherical campuses.
Carpooling introduction	**2017-2020**: some survey on students and staff demonstrates a limited interest in carpooling. Some solutions have been implemented for institutional mobility. **2021-2024**: carpooling solutions should be implemented with a specific focus on students, which choice of housing mainly interested suburban or others municipalities. A pilot project has been activated in partnership with Municipality of San Benedetto Val di Sambro, to grant resident students a commuting system towards Bologna campuses
Parking capacity reduction	**2017-2010**: progressive park reduction policies have been established, with specific regards to huge parking area, as Filippo Re and Belmeloro. The reduction has estimated in overall 30%. **2021-2024**: further park reductions will be analysed. A new web application aimed to find in real time park availability will be realised, with which it will be reduced any time-consuming and emissions sources phases, related to the search for park availability in university districts.
Mobility communication	**2017-2020**: main institutional communication channels have been used to promote measures and survey on mobility (Instagram, Facebook, Twitter, web portal, Unibosostenibile portal, mailing lists for students and staff, students newsletter). **2021-2024**: International conference on sustainable mobility will be organized. Special news section will be available to share with university staff transport network condition and congestions.
Sharing mobility applications	**2017-2020**: it has not been applied car sharing solutions focused on commuters. Only car sharing method has been introduced for car fleet management.

	2021-2024: with the aim to improve accessibility toward peripherical campuses, specific public car sharing agreement will be applied for commuters

Table 2.1: Three years Mobility management agreement – Goals and state of implementation

The Agreement requires also that the University of Bologna undertakes to carry out constant monitoring of the implementation of the PSCL during construction, in collaboration with the Municipal Administration, on the basis of the indicators reported in Table 2.2.

Indicators	**2019**	**Difference to 2024**
Campus and sites number	17	0
Employers and students	94,000	0
Car parking lots within campuses	1,000	-200
Motorcycle parking lots within campuses	250	-50
Bicycles parking lots	7,000	+ 1,000
Number of institutional cars part of car fleet	70	-20
Number of institutional bicycles	10	+50
Commuting cars used /100 employers	10%	-5%
Commuting motorcycle used /100 employers	3%	0%
Commuting bicycles used /100 employers	18-20%	+10%
Commuting public transport users /100 employers	30%	+5%
Commuting urban bus users/ 100 employers	20%	0%
Commuting integrated bus + train users/ 100 employers	20%	0%
Commuting extra urban buses users/ 100 employers	2%	0%
Commuting train users/ 100 employers	10%	+5%
Commuting by walking / 100 employers	43%	0%
% survey compilers / overall employers	5%	15%

Table 2.2: Indicators defined between University of Bologna and Municipality of Bologna within mobility management agreement 2021-2024.

2.3 GHG emissions by transport sector

University of Bologna has previously calculated the overall carbon footprint produced by its activities, comprehending mobility impact, using the methodology proposed by the UI Green Metric Ranking (GMR). The UI Green Metric World University Ranking is a ranking on green campus and environmental sustainability initiated by University of Indonesia in 2010. Through 39 indicators in 6 criteria, UI GreenMetric World University Rankings prudently determined the rankings by universities' environmental commitment and initiatives.

The Rankings have seen a dramatic increase of participants from 95 universities in 35 countries in 2010 to 956 universities in 80 countries in 2021. The GMR utilizes a set of criteria that have been considered to be straightforward and simple to complete while still credible on critical indicators. In the current performance evaluation tool there are 39 indicators and 6 criteria i.e. Setting and Infrastructure (SI), Energy and Climate Change (EC), Waste (WS), Water (WR), Transportation (TR), and Education (ED). In particular TR indicators are structured to focus on transportation policy specifically aimed to limit the number of private vehicles.

The GRM indicators in transport are illustrated in Table 2.3, with evidences by University of Bologna.

Indicator		Range (underlined University of Bologna evidence)	UNIBO
5.1	Institutional cars (only vehicles with emissions)		28
5.2	Number of cars enter into campuses on a daily basis (only vehicles with emissions)		1,069
5.3	Number of motorcycles enter into campuses on a daily basis (only motorcycles with emissions)		306

5.4 (**TR.1**)	Total number of vehicles per university population	[1] >= 1 [2] < 1-0.5 [3] < 0.5-0.125 [4] < 0.5-0.045 <u>[5] < 0.045</u>	0.15
5.5 (**TR.2**)	Shuttle /buses existing services	[1] Shuttle service is possible but not provided by the university [2] Shuttle service is provided and regular but not free [3] Shuttle service is provided and university contributes a part of the cost [4] Shuttle service is provided, regular and free <u>[5] Shuttle service is provided, regular and zero emission</u>	[5]
5.6	Number of buses operative in campuses		23
5.7	Average passengers per buses/shuttle		33
5.8	Total number of institutional trips per day		172
5.9 (**TR.3**)	Grade of endorsement for Zero emissions vehicles	[1] Zero Emission Vehicles are not available [2] Zero Emission Vehicles use is not possible or practical [3] Zero Emission Vehicles are available, but not provided by university [4] Zero Emission Vehicles are available, and provided by university and charged <u>[5] Zero Emission Vehicles are available, and provided by university for free</u>	[5]
5.10	ZEV average tripping per day		6,673
5.11 (**TR.4**)	ZEV total number per overall university population	[1] <= 0.002 [2] > 0.002 to <= 0.004 [3] > 0.004 to <= 0.008 [4] > 0.008 to <= 0.02 <u>[5] > 0.02</u>	0.223
5.12	Total sqm of parking lot [m^2]		2,078.86

5.13 (**TR.5**)	Total Parking lot surface percentage on overall campuses surface [%]	[1] > 11% [2] < 11-7% [3] < 7-4% [4] < 4-1% [5] < 1%	0.029
5.14 (**TR.6**)	Reducing parking area programs within last three years (2018-2020)	[1] Not applicable [2] Program is preparation [3] The program resulting in less than 10% decrease in the parking area [4] Program resulting in 10-30% decrease in the parking area [5] The program resulting in more than 30% decrease in the parking area or parking is restricted	[5]
5.15 (**TR.7**)	Number of mobility initiatives aimed to reduce private commuting vehicles	[1] Not applicable [2] 1 initiative [3] 2 initiatives [4] 3 initiatives [5] > 3 initiatives, or initiative is no longer required	[5]
5.16 (**TR.8**)	Pedestrian paths	[1] Pedestrian paths are not applicable [2] Pedestrian paths are available [3] Pedestrian paths are available and design for safety [4] Pedestrian paths are available, design for safety and convenient [5] Pedestrian paths are available, design for safety, convenient, and in some part disabled-friendly features	[5]
5.17	Approximate daily journey distance covered by vehicles within campuses [km]		5

Table 2.3: GMR indicators and University of Bologna evidences

The GRM methodology is based only on two macro-areas: energy consumed and transport, divided by car, bus, and motorcycle (UI Green Metric Rankings, 2020). Standard emission factors are then considered for each item. It should be immediately evident that the calculation methodology proposed by GMR is simpler compared to that required by international standards such as the GHG Report and ISO 14064. Green Metric considers electricity and transport without distinguishing between different scopes. In particular, the items of Scope 1 are not considered, items of Scope 2 are limited to overall energy consumption, and the ones of Scope 3 are not distinguished between university-owned and non-owned vehicles. Through the previous GMR criteria, the University of Bologna had different results calculated during the past years, as shown in Table 2.4.

Year	Emission from Electricity Usage per Year	Emission from Transportation per Year — BUS	Emission from Transportation per Year — Car	Emission from Transportation per Year — Motorcycle	Total Emission per Year/t CO2
2017	35,506	1,271	55	0.00	36,833
2018	35,669	1,271	1,478	0.00	38,419
2019	35,926	448	456	73	36,905

Table 2.4: University of Bologna carbon footprint calculated using Green Metric Ranking.

Due to the high level of structural complexity and wide territorial distribution, it has been necessary to review the calculation methodology proposed by the Green Metric.
A new carbon footprint calculation methodology has been carried out by University of Bologna, according to EN ISO 14064:2019 and GHG Protocol, to apply an overall assessment and to measure the environmental impact of policies and actions taken. The calculation criteria have been also applied to analyse and measure in quantitative terms the environmental impacts generated by University of Bologna in the function of COVID 19 – containment measures, such as lockdown and the reduction in in-presence activities (Battistini et al., 2022).
The new calculation has been carried out for the different three modes of transport considering polluting and relevant (car, bus, and train), as indicated in synoptic table 2.5.

GHG Emission Categories	Activity Subset	Activity Data [km]	Emission Factors $[\frac{\mathrm{kg\ CO_2e}}{\mathrm{km.passenger}}]$	tCO2e
Emissions from employees commuting	Consumption by car	1,959,953	0.1647	322.80
	Consumption by bus	33,599	0.099	3.35
	Consumption by train	2,123,282	0.0486	103.19
	Total			429.35
Emissions from students commuting	Consumption by car	4,962,292	0.1647	817.29
	Consumption by bus	2,422,994	0.0997	241.57
	Consumption by train	13,291,853	0.0486	645.98
	Total			1,704.85

Table 2.5: GHG emission in transport sector.

A new online survey was developed to better investigate how often students and teaching and administrative staff (employees) travelled to the university in 2020, by different means of transportation and the journey average distance. The questions of the survey aimed to investigate: the professional role; the place of study/work (which answers were structured in multiple choice format, offering wide options on all cities with campuses); how many times on a weekly and monthly basis in-person activities in the university were organized, considering all activities (work, internship, attending lectures, sitting exams, studying in the library, tutoring, etc.); which transport mean has been used for the home–university commuting journey (on multiple choice); km of the commuting journey; and, in spite of the COVID-19 pandemic, if any activity was conducted in person in 2020.

A statistical analysis of the answers was carried out for all the questions asked in the survey to understand the accuracy of the data and how well they represented reality. The survey results have been useful to calculate the activity data for the transport sector for each mode of transport, which are the following:

Total annual trip travelled = total km travelled per day × frequency × round trip

Total annual trip travelled = average km travelled per day × average daily frequency × 4 weeks × average monthly frequency × 2 where:

- "frequency" represents how many times on average a person came to the university physically during the year of reference and it is calculated as the result of daily frequency, weekly frequency, and monthly frequency;
- "round trip" is indicated with 2 since the questionnaire explicitly asks whether the return used the same means or not;
- "total annual km travelled" by students commuting and teaching and administrative staff (employees commuting): the calculation was carried out for the three different modes of transport considering polluting and relevant (car, bus, and train).

Total kilometers per each category has been reported in Tables 2.6 and 2.7.

Type of Vehicle	Average km	Average Daily Frequency	Average Monthly Frequency	Total km per Person	Total km of All Respondents
Car as driver	20	2.5	5	2,000	204,000
Car as a passenger	30	2	5	2,400	12,000
Bus	3	2	5	240	3,360
Train	70	2.5	5	7,000	217,000
	Total				424,360

Table 2.6: Total km for teaching and administrative staff by mode of transport in 2020.

Type of Vehicle	Average km	Average Weekly Frequency	Average Monthly Frequency	Total km per Person	Total km of All Respondents
Car as driver	20	2	3.5	1,120	120,960
Car as a passenger	20	3	3.5	1,680	15,120
Bus	12,5	2,5	3.5	875	63,000
Train	50	2,5	3	3,000	339,000
Total					522,960

Table 2.7: Total km for student by mode of transport in 2020.

Further analysis has been defined to estimate total kilometers traveled by the university community, including those who did not participate in the survey, based upon different assumptions: for each category of respondents to the questionnaire, the percentage frequency of the provided response in the choice of the means of transport have been taken into consideration, as illustrated in Table 2.8; the percentages of the previous point were then applied to the consistency on to the overall amount of people belonging to the teaching and administrative staff and students of 2020 (Tables 2.9 and 2.10).

Type of Vehicle	**Teaching and Administrative Staff**		**Students**		**Total**	
	Number of Answers	Percentage Ratio	Number of Answers	Percentage Ratio	Number of Answers	Percentage Ratio
Car as driver	102	42%	108	16%	210	23%
Car as a passenger	5	2%	9	1%	14	2%
Bus	14	6%	72	10%	86	9%
Train	31	13%	113	16%	144	16%
Other	90	37%	385	56%	475	51%
TOTAL	242	100%	687	100%	929	100%

Table 2.8: Main means of transport used on the way home to university in 2020.

Total Respondents			**Estimated attendance for 2020**
242			**2333**
Type of vehicle	Total respondents by type of vehicle	Percentage over total respondents	People calculated as a % of the estimated attendances for 2020
Car as driver	102	42%	980
Car as a passenger	5	2%	47
Bus	14	6%	140
Train	31	13%	303
TOTAL	152	63%	1,470

Table 2.9: Estimates of teaching and administrative staff using the different types of transport in 2020.

Total Respondents			Estimated attendance for 2020
687			27,691
Type of vehicle	Total respondents by type of vehicle	Percentage over total respondents	People calculated as a % of the estimated attendances for 2020
Car as driver	108	16%	4,431
Car as a passenger	9	1%	277
Bus	72	10%	2,769
Train	113	16%	4,431
TOTAL	302	44%	11,907

Table 2.10: Estimates of students using the different types of transport in 2020.

The item "Car as a passenger" has not been considered for the final calculation of CO_2 emissions because it is not relevant, representing only 2% of the Unibo staff and 1% of the student population who validly answered the survey. The proportion performed is:

Total respondents by type of vehicle/total km of all respondents by type of vehicle = People calculated as a % of estimated attendances by type of vehicle/x

Where *x* is the total km travelled for all the estimated population by type of vehicle.

Applying the above equation, the following results have been obtained, as well as the activity data needed to calculate emissions:

- 1,959,953 km by teaching and administrative staff during 2020 traveled by car;
- 33,599 km by teaching and administrative staff during 2020 traveled by bus;
- 2,123,282 km by teaching and administrative staff during 2020 traveled by train;
- 4,962,292 km by students for the whole year 2020 traveled by car;
- 2,422,994 km by students for the whole year 2020 traveled by bus;
- 13,291,853 km by students for the whole year 2020 traveled by train.

Subsequently, all these activity data were multiplied by the relevant emission factor, which we found to depend on the type of polluting medium used.

The final calculation of total emissions from the Unibo in 2020 for transport sector has been estimated in 2,143 on an overall tCO2e emission of 16,467 tons of CO2e, which become 15,753 tCO2e considering the offset and avoided emission caused by the internal production of energy from renewable sources fed into the national grid, as shown in Table 2.11.

Emissions category in transport sect.	**tCO2e**
Emissions from employee commuting	429
Emissions from student commuting	1,705
Total emissions by commuting	2,143

Table 2.11: Unibo carbon footprint related to 2020 for transport sector.

In Figure 2.5 it has been reported the relevance of emissions produced by commuters in comparison to other activities sources.

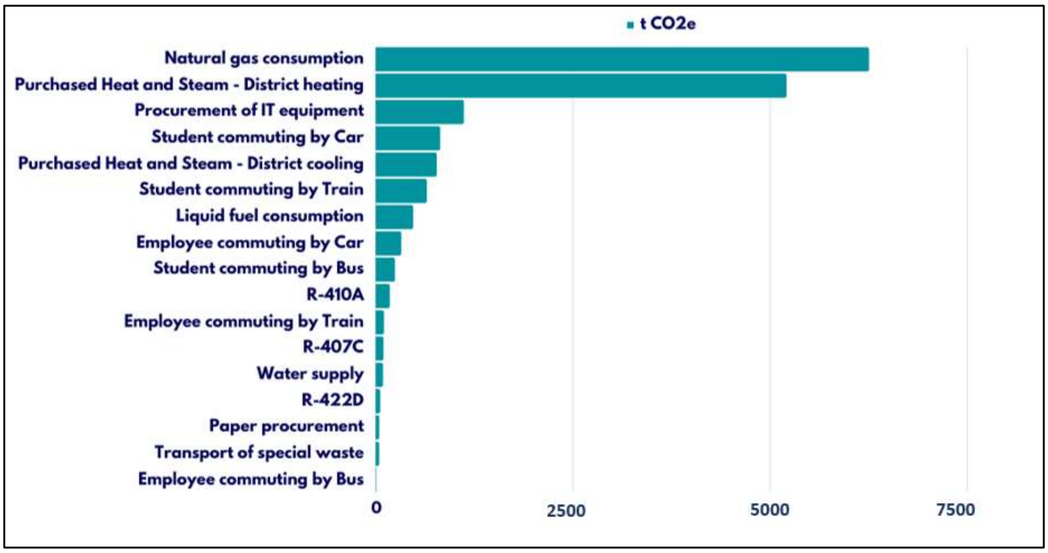


Figure 2.5. Tons of CO_{2e} by activity subset.

A comparison between 2020 and 2018 has been also carried out to establish the impact of COVID-19 on each emissions source, as indicated in Figure 2.6.

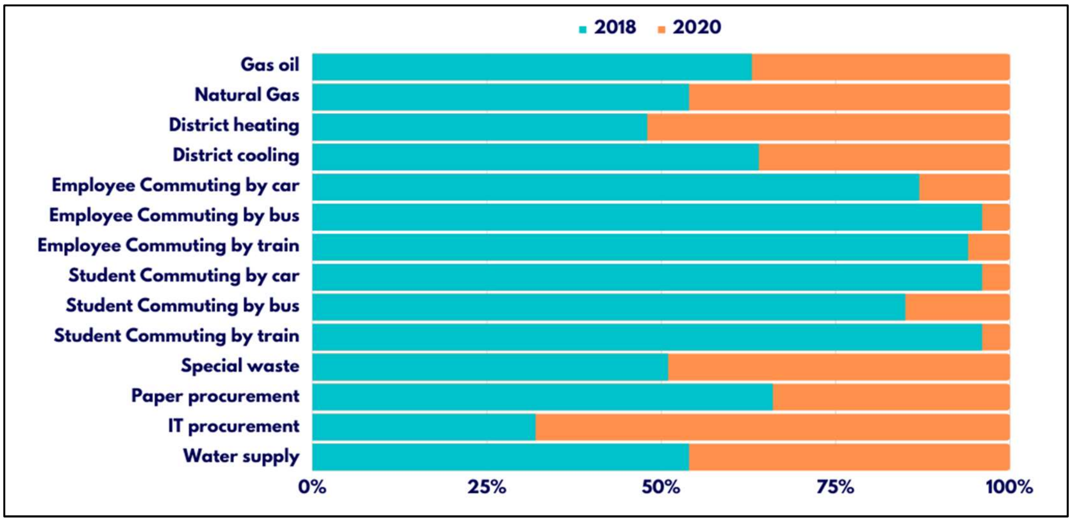


Figure 2.6. Comparison of 2018 and 2020 emissions by sub activity.

In these terms, in 2018 emissions from all the students and employees commuting activities are clearly higher. In particular, it should be justified by the fact that the university remained closed or partially closed for many months in 2020, conducting almost entirely remote activities.

The need to undertakes on enhancing cycling for University of Bologna, finding more efficient approach able to convert from private cars to active mobility, has been demonstrated by the impact of commuting transport in 2018, a year of regular activities in presence. The project Almabike, object of the present thesis, intends to represent a step in innovative methodologies able to orient operative measures and funding in more appropriate and efficient term to increase the cycling modal share.

In next chapter University of Bologna modal share and related analysis have been illustrated.

Chapter 3. Mobility behaviours in University of Bologna

3.1. Introduction

3.1.1 The role of behavioural analysis in mobility strategies

The Study of behaviors in transportation is a key factor in accomplishment of efficient mobility strategies. In particular behaviors analysis orients the travel mode choices and consequently represents a component factor of Transportation Demand. Its comprehension permits to break the habits and drive to modal switch, specifically towards ecological means of transportation.

According to the recent models in psychology, such as the comprehensive action determination model (Klockner & Blokbaum, 2010) or the conceptual model of travel behavior (Van Acker et al. 2010), travel mode choice depends on the combined effect of different predictors, such as the interaction between intentional processes and habitual processes. The role of psychological variables in predicting mobility behaviors has been supported in several previous studies. Doran and Larsen (2016) showed the crucial role of personal values in explaining a relatively large proportion of variance for eco-friendly mode choice (Lind et al., 2015), clustered participants into three different group of transport mode according to their personal values which successfully explained their travel mode choice. Abrahamse et al. (2009) showed that car choice for commuting was mainly explained by perceived behavioral control (PBC), while personal values explained the intention to reduce car use. Additionally, several psychological studies showed the critical role of habits in determining the use of different travel modes (Klockner et al., 2010; Klockner et al., 2011; Simsekoglu et al., 2015). A habit can be defined as an automatic response, learned by repetition, under constant circumstances of a motivated action to attain a specific goal (Verplanken et al., 1997). Although this concept is rooted in behaviorism, building a habit is a cognitive-motivational process in which control of the action relies on the environment (Wood et al., 2016). Considering all the other factors being equal, the more a behavior is rewarded (e.g., car use), the more likely it will be repeated when a specific contextual stimulation is present (e.g., commuting route) (Klockner et al., 2013). A study by Schuitema et al. (2007) showed that, despite the rising costs of driving a car, regular car users had no intention of changing their mode of travel. In line with this assumption, several studies have also investigated the "tunnel vision" effect (Lind et al., 2015; Verplanken et al., 1997). A plausible explanation could come from the automatic processes of using the car in a stable environment. In general, the stronger is the habit, the less is the impact of the intention to change a specific behavior (i.e., car use reduction). That is, once car use has turned into habitual behavior it is difficult to break this habit and persuade the car user to seek out for alternative travel mode options. From a behavioral change perspective, identifying interventions capable of breaking habits may, therefore, be as important as employing effective interventions targeting motivation. A series of studies (Verplanken et al., 2008; Verplanken et al., 2016; Walker et al., 2015) based on the habit discontinuity hypothesis have demonstrated how contextual changes, e.g., changing residence, can weaken habits and create "a window of opportunity" where people can redefine their mobility patterns and embrace a behavioral change. In our study, we explored how this "window of opportunity" could have affect car use choice at different commuting distances among the present academic population, composed of people who have recently moved to study/work and people who have lived in the area for years. The accessibility to other modes of transport may be critical for a behavioral change to occur (Hoffmann et al., 2017). For example, studies have found that people who live outside the urban area with limited access to public transport (or other type of sustainable transport services) are more willing to use the car for their trips (Dargay et al., 2007; Mann et al., 2012). In terms of accessibility, several studies have found a significant impact on reducing private car use by introducing a public transport season ticket (Bamberg et al., 2003; Hunecke et al., 2007; Kuhnimhof et al., 2012; Zhou, 2012). Furthermore, considering built environment characteristic where people live, population density has been identified as an explain mode choice (Ramezani et al., 2018; Susilo et al., 2007) and car use factor (Dargay et al., 2007). The idea is that the higher the population density, the higher the likelihood to use alternative and sustainable modes of transport due to a high traffic density, low travel speed, and better accessibility of public transport (Chen et al., 2008; Santos et al., 2013). Finally, researchers have introduced other external constraints that may determine travel mode choice. With a clear reminder to the ipsative theory (Hoffmann et al., 2017), objective and perceived situational conditions may further constrain mode choice. For example, some studies have found that the presence of children in the household increases the likelihood to use the car (Kim et al., 2008; Whalen et al., 2013).

Understanding i.e. how the presence of people with disabilities or special needs, as well as the presence of children and older people to care, could affect strongly commuter mode choice. In particular is impacting in terms of reducing private car uses, shifting toward active mobilities.

3.2 Survey on mobility choices and attitudes: the case of GOTOUNIBO 2017

In 2017, the University of Bologna published a document, describing and reporting on the institutional activities useful to the achievement of the Sustainable Development Goals, according to the action program of the 2030 Agenda and in line with the 2016-18 Strategic Plan. The Report “U.N. Sustainable Development Goals” reports, in fact, the plan of activities with respect to the 17 Objectives for Sustainable Development of the United Nations, in which the values of sustainability that the University carries forward, such as the improvement and protection of the territory, the welfare of the community, the promotion of an economy of development based on knowledge, social equity and the ability of those involved to work in a way effective for the common good have a strategic value of absolute interest.

One of the University's commitments is to build urban mobility with a low environmental impact. To effectively contribute to the reduction of emissions into the atmosphere, the University of Bologna promotes the use of public transport, cycle mobility and low-impact forms of mobility for both service and other travel Home – Work/Place of study, as mentioned in Chapter 2.

Since 2007, through a web questionnaire addressed to all staff and students, the transport methods and needs of university users for home-work/study journeys have been analysed annually. From this analysis derive the strategies defined in the annual planning Home-Work/Study Commuter Plan, shared with the Municipal Administration. In 2017 a new questionnaire called GOTOUNIBO was developed with the aim of evaluating Home-University mobility in all categories, universities employers and students. The objective of the survey was to have information useful for guiding and evaluating mobility management policies and for improving the mobility of those studying and working at universities. This document reports the results of the first GOTOUNIBO survey of 2017.

The 2017 survey has been developed through the Qualtrics^{XM} software, a platform designed to optimize research around the customer, employee, product, and brand.

Data collection was initiated after approval from the Ethical Committee of the University of Bologna obtained on 25th April 2017. The introduction section to the questionnaire contained the privacy instructions and the related informed consent. The following text has been formulated undergone to University Data Protection manager approve:

"*The questionnaire is anonymous and the data will be used in aggregate form, solely for the purposes of research activities. The results of the survey will be published on the University website of the service dedicated to sustainable mobility issues. For any information or clarification, you can contact Roberto Battistini, owner of the following research project and data collection. You can contact the email address: info.mobilitymanager@unibo.it. Confirmation is mandatory in order to start completing the questionnaire. It is noted in accordance with Norm 675/1996 and the subsequent Legislative Decree 196/2003, that all the information collected they will be used exclusively for research purposes by the University of Bologna. The data collected in the scope of this survey, moreover, are protected by statistical confidentiality and therefore* *cannot be communicated or externalized except in the aggregate, so that no individual reference can be made, and they can be used only for statistical purposes (art. 9 of legislative decree 6 September 1989, n. 322)." The information on data processing was available in the attachment (in Annex at the web page…*)"

The online questionnaire addressed to three different groups within the organizational context: (i) students, (ii) professors, and (iii) university staff. A link to the online questionnaire was also published on the website of the University Mobility Service, where participants could access information about the purposes of the research, data protection, and privacy issue statements. The link was sent by university emails to 90,488 people – students and staff.

In 2017 the reporting document carried out within the University of Bologna (Unibo, 2016) registered a total of 84,724 students, 5,376 from international courses and 4,161 enrolled in post-graduate courses graduate. Regards academic and administrative staff (TA staff), was reported a total of 2,819 professors, in which 994 were researchers and 2,945 administrative staff.

At the end of the surveys, 4772 people decided to join by completing the questionnaire. In 2017 survey, as highlighted below, the number of questionnaires considered valid has been 4,135, with a participation rate of about 4% of the entire university population. Compared to the last survey aimed at the elaboration of the PSCLS (2014) in which 6091 people participated, the number of questionnaires suffered a decline of just over 20%. It should be noted that the respondents joined on a voluntary basis.

The Survey has been structured on 13 different sections with overall 113 questions.

The 13 sections are:

1) Main home-work transportation means used, complete of distances and time.
2) Trip chain (sequence of transportation means choose along the overall home-work daily journey). It has been analysed by the perspective of different seasons (autumn/winter vs spring/summer).

3) Stop and specific needs along their Home-work journey, which permit to understand constrains related to the family needs of the participants.
4) Qualitative satisfaction information regarding the trips.
5) Institutional mobility needs and choices.
6) Sharing mobility preference analysis, in which evaluate existing habits about car sharing, bike sharing and carpooling, and users' attitudes for application of these means in daily home-work trip.
7) Attitudes on using mobility supporting applications, with specific information about journey path planners.
8) Mobility capital, intended as attributes, i.e. driver license or public transport annual ticket, used on the daily basis trips.
9) Qualitative preferences and opinions about transportation means.
10) Road safety perception on different transportation means.
11) Preferences on strategic sustainable mobility measures.
12) Insights on traveling by car in which places, times and costs of parking as well as fuel were explored. This section was dedicated exclusively to those who had selected the car, motorbike or scooter and bicycle as the main modality (concerning parking places and times).
13) Socio-demographic general information.

Figure 3.1 shows the frequencies of participants' gender and age for the entire sample as well as for each academic category.

	Age		Gender			Total
	M (min; max)	*SD*	Male (%)	Female (%)	Missing (%)	Freq. (%)
Students	22.98 (18;68)	3.60	1196 (40.7%)	1745 (59.3%)	87 (2.9%)	3028 (73.2%)
Professors	49.83 (33;74)	9.53	220 (58.5%)	156 (41.5%)	2 (0.5%)	378 (9.1%)
University staff	48.26 (26; 77)	8.25	234 (32.7%)	481 (67.3%)	14 (1.9%)	729 (17.6%)
Total	29.96 (17;77)	12.71	1650 (40.9%)	2382 (59.1%)	103 (2.5%)	4135 (100%)

Figure 3.1. Age and gender frequencies and percentages per status category.

Dynamic origin-destination has been analysed on a macro level. In particular the region of origin of participants has been represented in Figure 3.2, as well as the metropolitan area of origin in Figure 3.3, while campuses of destination has been illustrated in Figure 3.4.

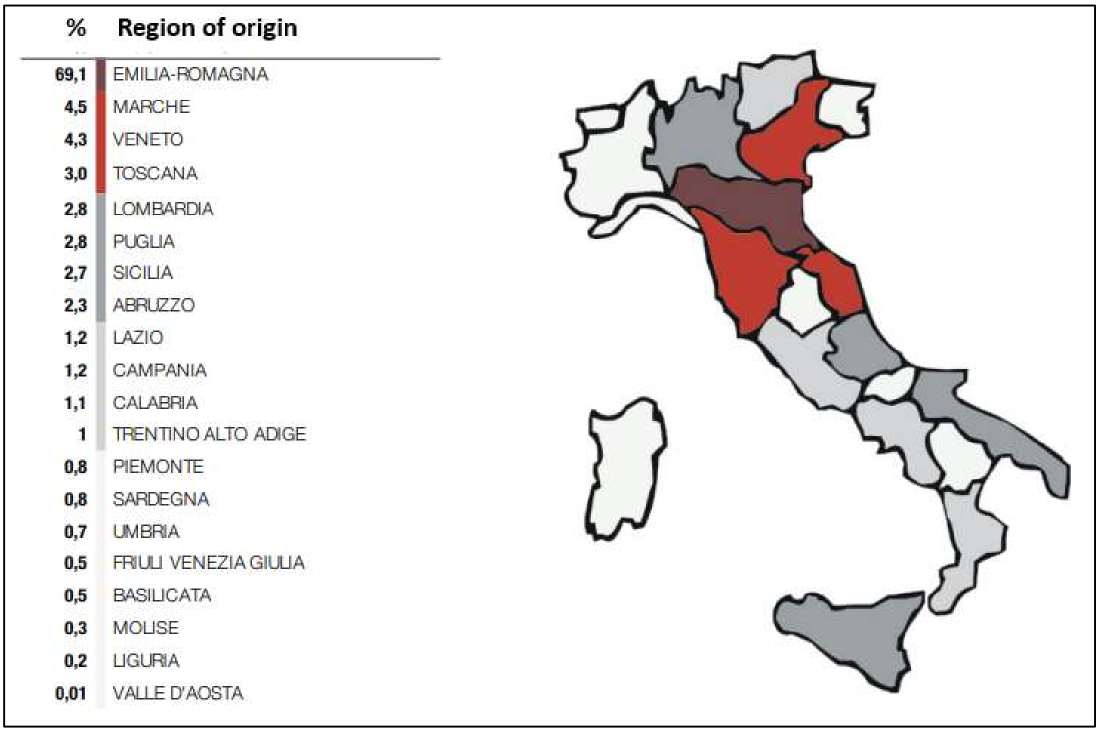


Figure 3.2. Regions of origin.

Figure 3.3. Metropolitan areas of origin.

Figure 3.4. Campuses of destination.

The average time to reach campuses has been estimated in 50 minutes. Through the analysis conducted has been also possible to recognize that academic staff and students presented an average time trip major than administrative staff, about 6 minutes of difference. Administrative staff had an average time of 44 minutes.

In terms of distances factor, more than 1/3 of participants reach the campuses in less than 5 km (28,7%). About 30% moreover presented more than 30 km per day, as illustrated in Figure 3.5.

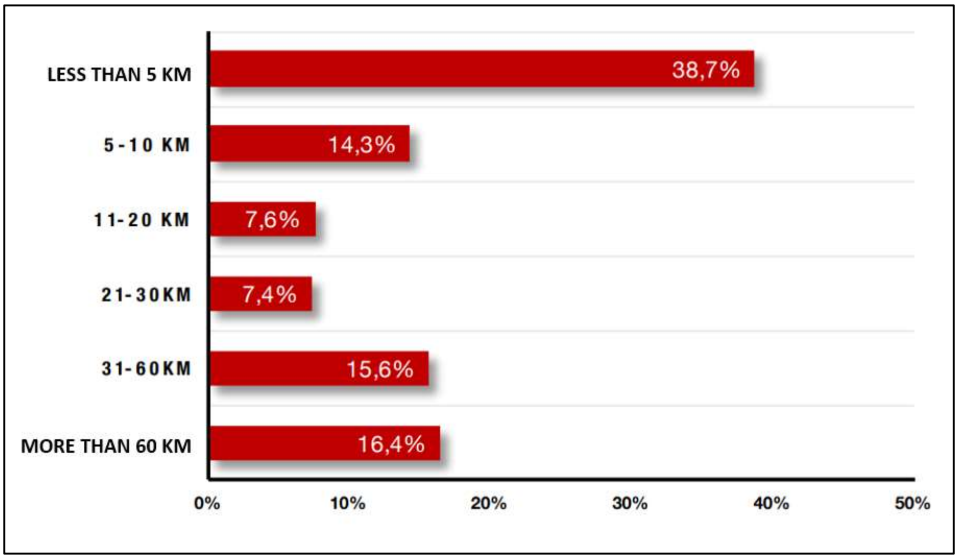


Figure 3.5. Distance in km to reach the Campuses for the entire university community.

In details, separating the data on the distances covered, on the basis of the role, it emerged that around 40% of the students and around 45% of male and female collaborators declared that they travel less than 5 km to reach the campuses. The percentage of academic and administrative staff, which travels were less than 5 km, were about 10% lower compared to students and collaborators.

Just over 30% of students and about 26% of male and female collaborators reported that their trip had a length more than 30 km, a distance covered by about 36% of the professors and by the 22% of administrative staff. In general, female administrative staff, co-workers and similar categories, tended to cover shorter distances to reach the University with respect to students and professors. It appears that 59.3% of male and female collaborators and 56.1% of administrative personnel reached the University in less than 10 km (compared to 51.9% of students and 50.2% of professors/researchers), while 35.8% of professors and 34.4% of students travel at least 30 km to reach the campuses (compared 26% of male and female collaborators and 22.3% of TA personnel).

Within the questionnaire, a relevant section was dedicated to deepening knowledge in terms of main transportation mean used primarily. The term “main transportation mean” meant the mode in which most of the journey was covered. This analysis has been carried out taking into consideration the weather factors, with the aim of highlighting possible variations in terms of choice of the main vehicle based on the role.

Regardless of the season of the year, the mode of transport most used by participants is the train: 31.5% of respondents travel most of the distance to reach the University by train. The most used transport is the bus with 19.4%. 17.5% travel most of the C-LS journey on foot, while 15.7% by bicycle. 12.5% travel by car and 3.2% travel by motorbike or scooter.

The question addressed as “In case of bad weather (e.g. rain), still use the same main mode of transport for travel most of the distance?”, presented 83% of affirmative answers. Respondents who edited the mode of transport in case of bad weather, have also indicated the preferred mode of transport used. Overall, in the event of bad weather, 31.4% of respondents declared that they travel by train, 27.4% by bus, 19.7% on foot and 15.1% by car. In case of bad weather, an increasing use is observed for the bus, which passes from 19.4% to 27.4%, for the car, which passes from 12.5% to 15.1%, and by walking, which goes from 17.5% to 19.7%. The modes of transport that are most affected by adverse weather conditions are respectively: the bicycle, which goes from 15.7% to 4.9%, and the motorcycle/scooter, which goes from 3.2% to 1.1%, as indicated in Figure 3.6.

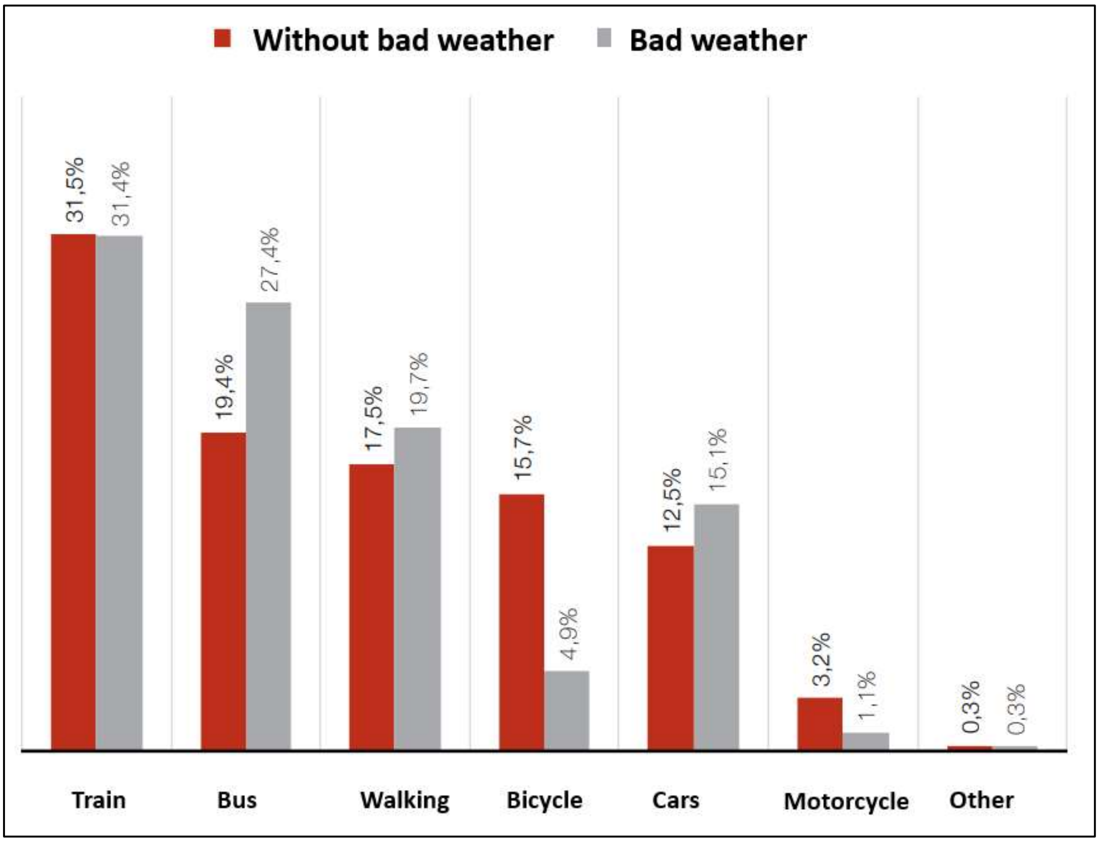


Figure 3.6. Impact of weather condition on travel mode.

Focusing on the main transportation mean, the variations based on bad weather follow the percentages above described according to the role of the participants. In detail, it can be observed that variations are totally absent for train mean (+0.2% on average).

A very similar trend is found for those who decided to reach the campuses by walking (+2.1% of average), with the exception of students, collaborators and collaborators who show an increase of 3 points percentages in case of bad weather.

Finally, if the use of the motorcycle or scooter and, even more markedly, of the bicycle suffered a relevant reduction of use during days when the weather was adverse, respectively down by -2.7% and -10.7%, a completely opposite trend can be instead observed for those who decide to use the bus or the private car to reach the university in case of bad weather, respectively up by 7.3% and by 4.5% (Figures 3.7, 3.8 and 3.9).

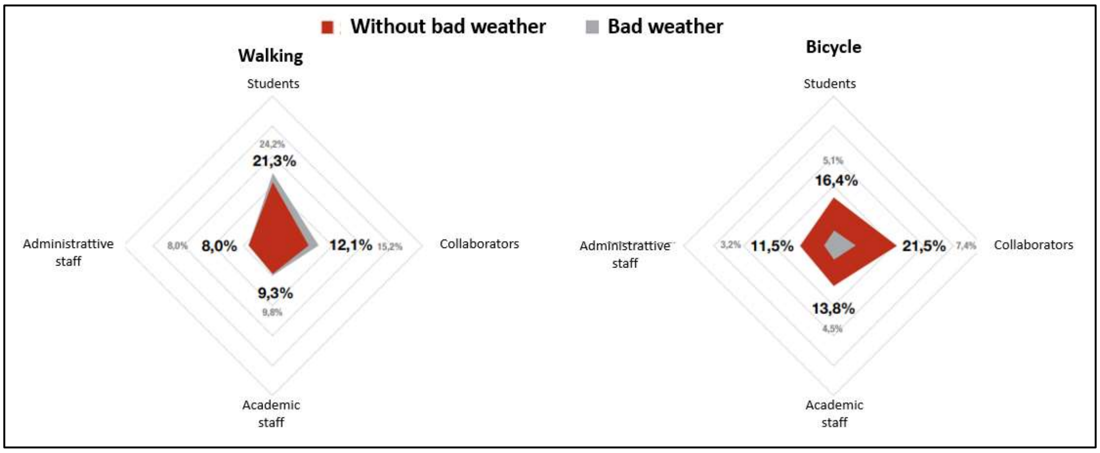


Figure 3.7. Weather impact on cycling and walking per category.

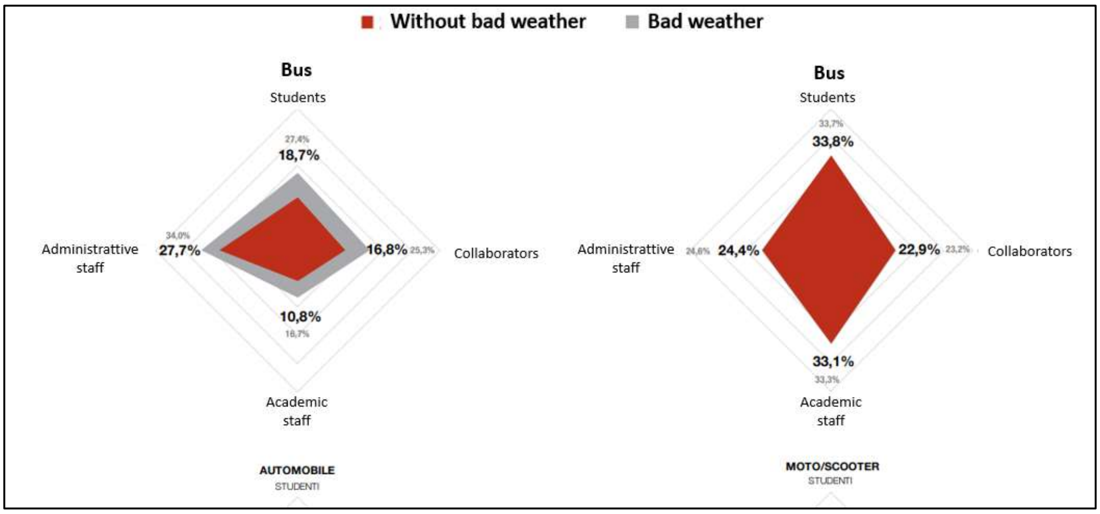


Figure 3.8. Weather impact on bus and train means per category.

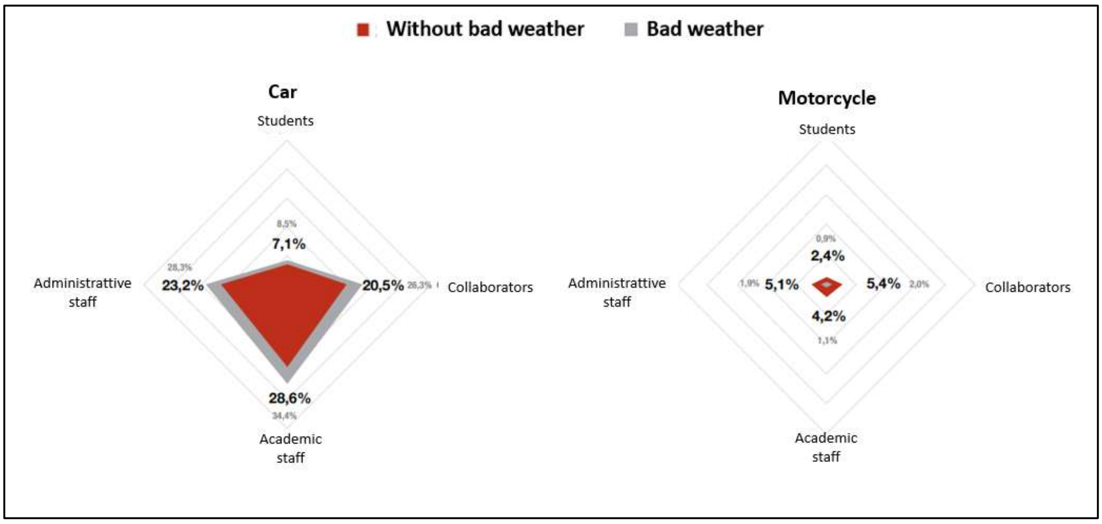


Figure 3.9. Weather impact on bus and train means per category.

In general, regardless of the weather conditions, respondents traveling less than 5 km to reach the University they generally travel on foot (42.3%), by bicycle (31.8%) and by bus (16.9%). In case bad weather, the percentage of bus use doubles to 31.6%. There is also an increase of traveling on foot which drops to 47.5% and a decrease in traveling by bicycle which becomes 9.8%. Participants who travel 5 – 10 km to reach the University generally travel by bus (43.1%), bicycle (22.1%) and car (19.7%). In case of bad weather just over half of the participants travel by bus while about 25% prefer the car. Respondents who travel 11 – 20 km to reach the University generally travel by bus (39%), car (37.8%) and train (14.9%). In case of bad weather, a slight increase in bus trips which pass to 42.9% and in those by car which pass to 39.3% is obtained.

The main modes of transport for those who travel 21 – 30 km to reach the University are the train (41.5%), the bus (31.2%) and the car (24.8%). The percentages of use of these modalities of transport do not undergo significant variations in the event of adverse weather conditions. Almost all of the respondents who travel 31 – 60 km and more than 60 km to reach the University travel by train (respectively 77.7% and 89.8%), only a smaller percentage use the car (respectively 13.6% and 5.6%). There are no changes in the use of these modes of transport in case of bad weather. For journeys of up to 10 km, most of the variations in the modes of transport are highlighted of bad weather. In general, the bicycle appears to be the most sensitive mode of transport to conditions adverse weather. The relationship among distance and main transportation mode is illustrated in Figure 3.10.

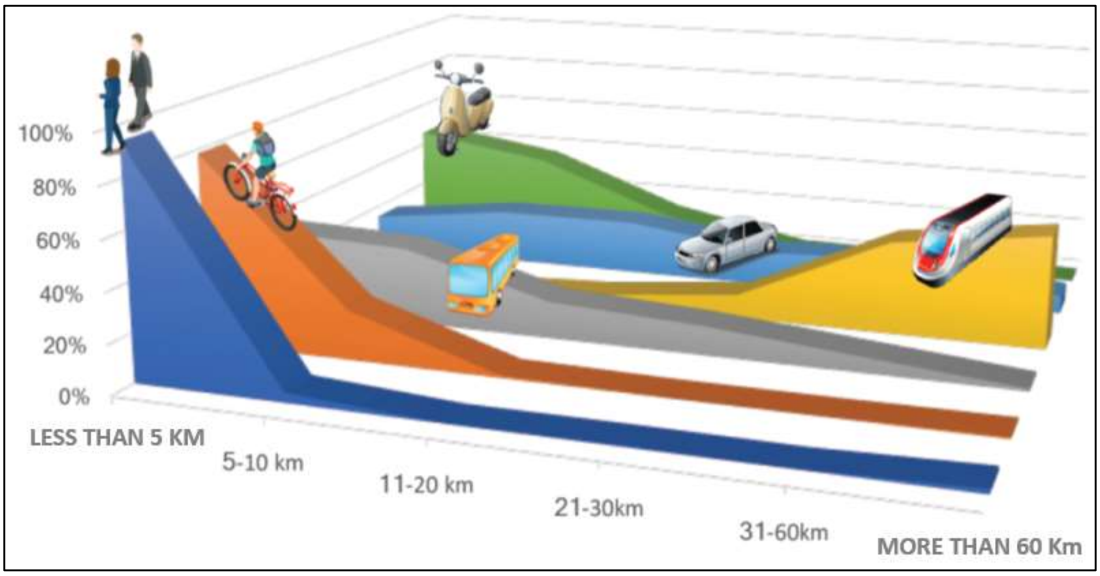


Figure 3.10. Relationship between transportation means and distances in not bad weather condition.

The section dedicated to the trip chain, i.e. the detailed description of the route, played a key role within the investigation. The participants had the possibility to describe, step by step, the modality of transport used, also indicating a rough estimate of the time and kilometres travelled. Consequently, it has been possible to understand travel habits in terms of unimodality and multimodality, with the further possibility of extrapolating the most used multimodal strategies, both during the cold and hot season. Considering the journey from Home to University, 48.9% of the interviewers declared that they arrived at their destination using a single mode of transport while 51.1% is related to multimodal travel solutions. Among the latter, 54% of students adopted multimodal travel solutions. More than half of male and female collaborators (60%), of professors (55%) and TA staff (52%) on the other hand, reported that they arrive at their destination using only one method of transport.

Going into the details of multimodal strategies, 14.9% of respondents report arriving at their destination using two modes of transport, 29.4% use three modes and 4.3% four modes of transport. Less than 1% of respondents arrive at their destination using five modes of transport, as indicated in Figure 3.11.

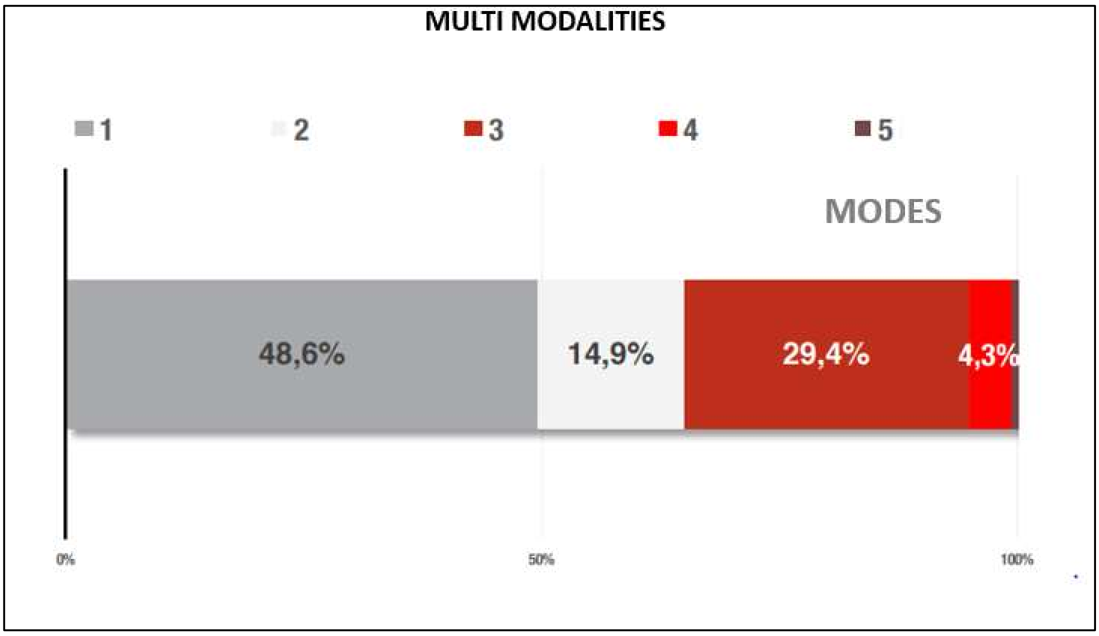


Figure 3.11. Single and Multimodalities distribution.

Investigating the issue based on the role, it emerged that around 30% of the students and 30% of the professors declare to arrive at their destination using three modes of transport, while 22% of female collaborators and 22% of administrative staff use three modes of transport. 18% of administrative staff, 15% of students, 13% of male and female collaborators and 10% of professors adopt bimodal travel solutions. 5% of students, 4% of administrative staff, 3% of professors and 2% of collaborators, declared to get to their destination using four modes of transportation.

The main unimodal and multimodal strategies adopted by the participants are reported below. However, the strategies adopted by less than 2% of the total sample are not presented. Considering those who reach the University with one mode of transport, 17% of the interviewees reach the University on foot; 11% of the interviewees reach the University by bicycle; 10% of the interviewees reach the University by car; 7% of the interviewees reach the University by bus; 2% of the interviewees reach the University by motorbike/scooter. In figures 3.12, 3.13, 3.14 and 3.15 have been illustrated the distributions of different trip chains.

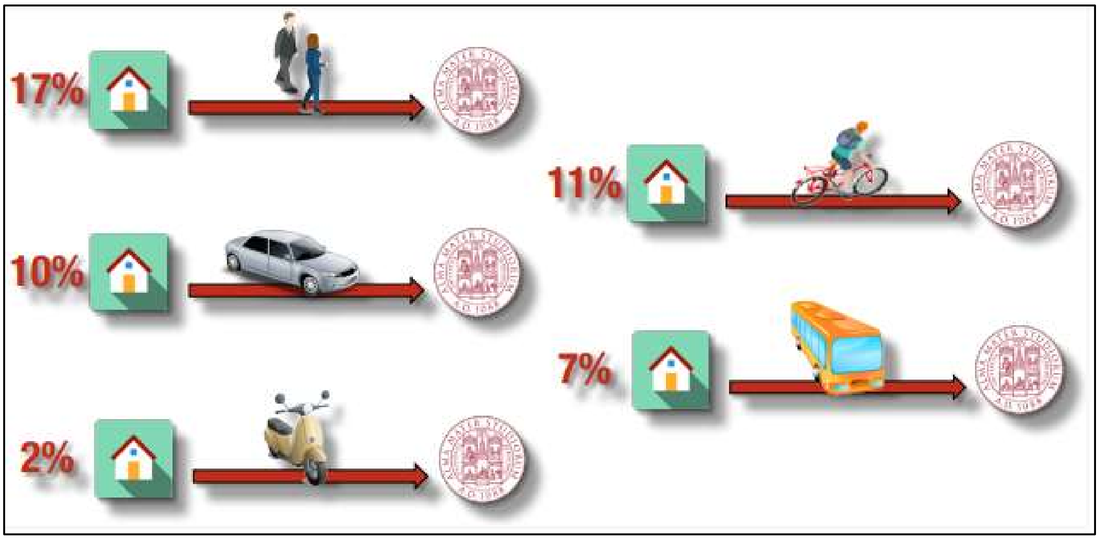


Figure 3.12. Single mode distribution among transportation means.

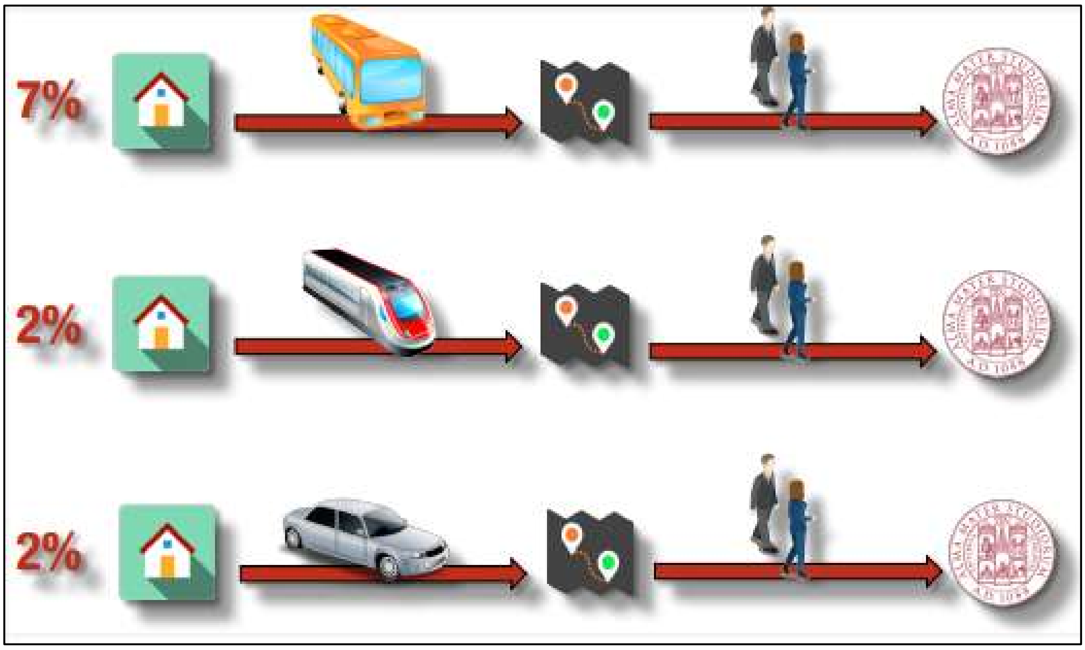


Figure 3.13. Bi-modal distribution among transportation means.

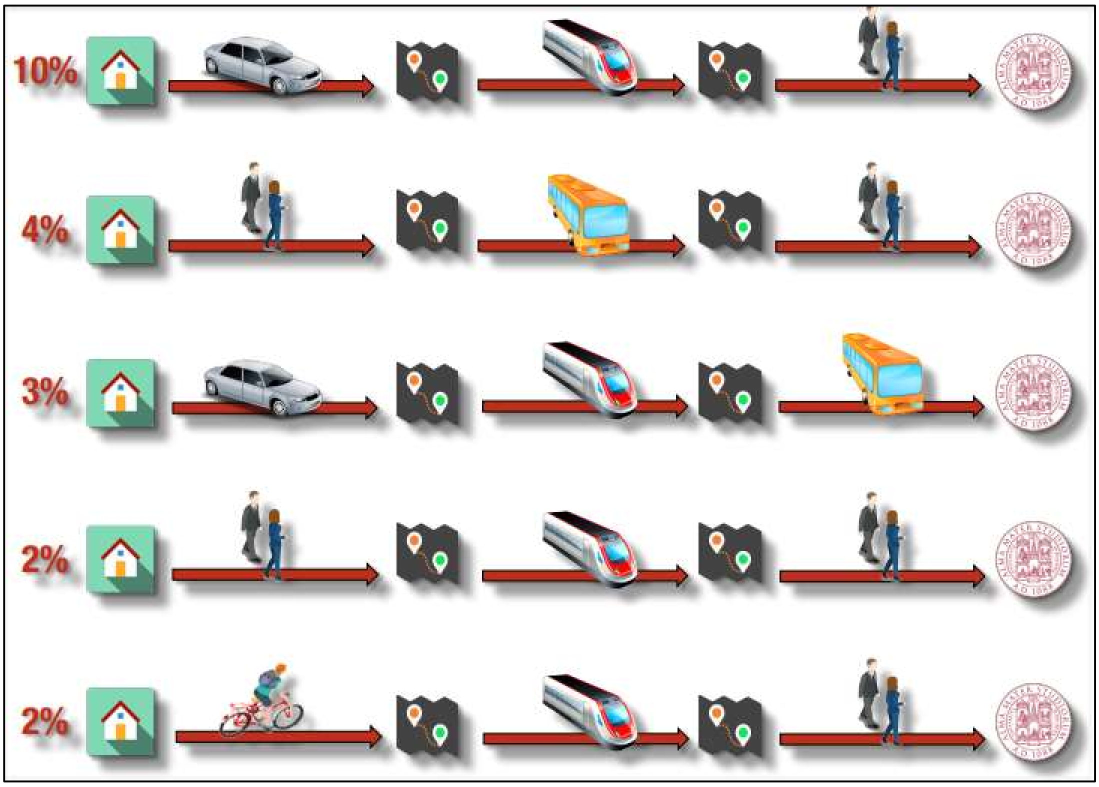


Figure 3.14. Three-modal distribution among transportation means.

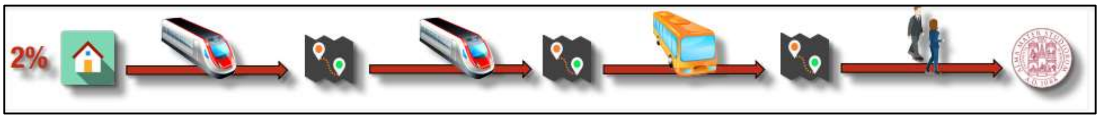


Figure 3.15. Four-modal distribution.

From the results it emerged that only 14% of the participants declare that they change their mode in the hot season. Among that 14% of seasonal influenced trips it has been possible to build the related tripchains.

Considering those who reach the University with one mode of transport, the distribution has been evaluated in: 18% of the interviewees reach the University by bicycle, 17% of the interviewees reach the University on walking, 8% of the interviewees reach the University by car, 5% of those interviewed reach the University by bus, 3% of those interviewed reach the University by motorcycle/scooter.

About two modes of transport the distribution has been evaluated as: 5% of the interviewees reach the University with a train-on-foot sequence, 2% of the interviewees reach the University with a bus-on-foot sequence, 2% of the interviewees reach the University with a car-on-foot sequence.

The section aimed to detecting possible stops or detours along the way to and from the campuses had the substantial purpose of understanding possible needs. In these terms, has been asked to participants if they normally need to make stops and/or if the presence of specific family needs (e.g. presence of children or elderly people) could influence the choice of vehicle or at least the journey itself. 36.3% of respondents declared that they make stops or intermediate trips on the way from home to the campuses (or vice versa). Considering the journey Home – University, 10.5% of the participants declared that they make intermediate stops, while on the return journey (University-Home), the percentage reached 32.8%.

Observing the data based on role, on the journey Home – Campuses, 19% of professors and 16% of administrative staff reported that they have done at least one stop, decidedly lower quotas for female collaborators and collaborators (10%) and students (8%). However, a different dynamic emerges from the return journey (University – Home) where 34% of male and female collaborators and 32% of students declared that they stop at least once.

In order to have a better understanding of the nature of the stops and/or detours made along the way, some possible family needs have been further analysed. In general, 11.4% of the sample reports specific family needs the basis of daily stops. Approximately 85% of the 440 participants who expressed this need indicated that the presence of children is particularly influential. The latter is the main cause behind stops and delays intermediate trips for administrative staff (37%), academic staff (23%) and students (20%). 39% of the questionnaire participants indicated that the presence of elderly family members is relevant in the home-campuses commuting. Most of them are Professors (19%) and administrative staff (15%). 24% of the participants indicated that the presence of disabled people or personal disability is influential in stops on the way home, especially for the student category (14%).

On a scale of 0 to 10 (0=not satisfied at all; 10=completely satisfied), participants were asked to express general satisfaction with the move from Home to University, subsequently analysing one series of specific characteristics of the route (e.g. duration, cost of the journey; degree of accessibility and connectivity).

A first interesting aspect that emerged from the results is the tendency to report general satisfaction on average higher than the individual aspects subsequently evaluated. It should be remembered that these percentages do not necessarily have to reach 100% because there may be cases in which several family needs are present at the same time and assistance, difficulty in moving and difficulty in taking means of transport. The distribution of qualitative answers for the satisfaction has been structured in different trip experience issues: duration, cost, accessibility, safety level, adequacy of infrastructures level and overall comfort, as illustrated in Figure 3.16.

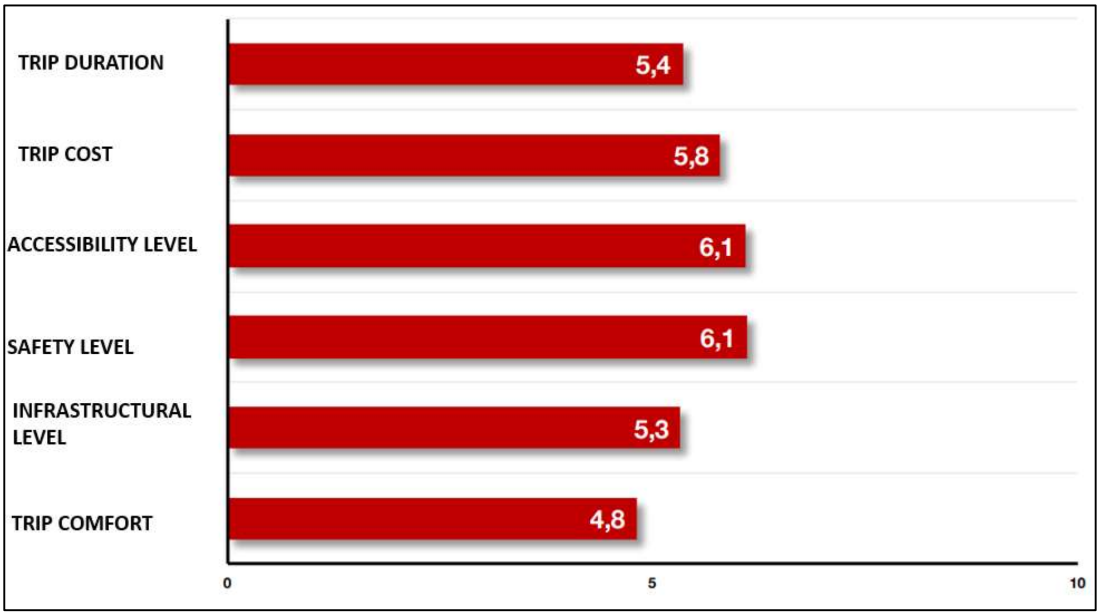


Figure 3.16. Satisfaction about trip experience.

From the categorization by role, it can be seen that professors (6.5), female and male collaborators (6.5) and administrative staff (6,9) were generally more satisfied with the Home - University path than students (6).

Regarding the safety issue of the Home - University path, all four categories analysed seem to agree with an average score of about 6. The same goes for accessibility and connectivity in the displacement, all categories reported an average score of 6.1. There is a disparity between the category of students and that of workers with regard to the cost of travel for moving: professors (6.5), female collaborators (6) and TA staff (7) reported a higher average score than students (5.3). Furthermore, the latter believe that the duration of the journey to reach the University was satisfactory only for a score of 5.1. For professors (5.7) and collaborators (5.7) and TA staff (5.8) the average score travel time was slightly longer. However the four categories considered agree with an average satisfaction of 5.3 with regard to the adequacy of the infrastructure in moving from home to university. Average satisfaction with travel comfort was 5.1 for professors, collaborators, collaborators and TA staff while it decreases further for students (4.6).

By categorizing the respondents according to the main mode of travel, it is interesting to note how in the different cases may vary the satisfaction of the various aspects analysed, as illustrated in Figure 3.17.

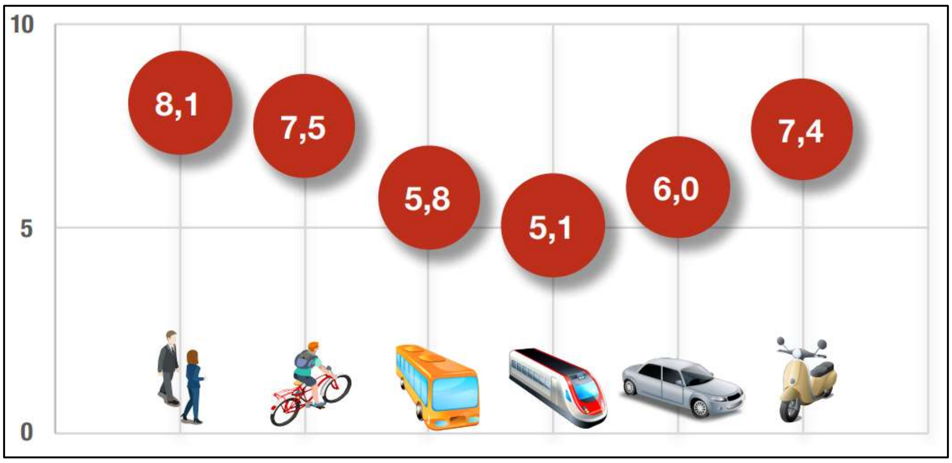


Figure 3.17. Satisfaction per transportation means used in home-work commuting.

About sharing mobility topic used in 2017 in home-campuses journey, participants were asked how often they used various types of shared mobility: car sharing, carpooling and bike sharing. To those who have never used these shared methods, they were asked to indicate how much they would intend to use them in the near future, in particularly focusing on the Home - University trip. In general, around 94% have never used the car sharing and/or bike sharing service, while around 5% of participants use these modes of transport only a few times a year. The most shared mode of transport used is carpooling, 11.1% of participants use it a few times a year and 2.9% monthly, however about 84% of the participants declare that they have never used it.

Looking at the percentages based on the role, on average, more than 90% of students, female collaborators, academic and administrative staff declared that they have never used bike sharing, while only one a small part of them (5%) say they have used this service a few times a year. About 10% of male and female collaborators used the car sharing service, but 7.5% of them only a few times a year. Approximately 94% of administrative and students, and academic declared that they never used these services. More in details, 95% of academic and administrative staff declared that they have never used carpooling, while about 20% of students, collaborators and seems that they used it. Indeed specifically about 17.9% of collaborators and 13.2% of students used in carpooling a few times a year, 4.1% of male and female collaborators and 3.5% of students used this service on a monthly basis.

The general attitudes towards using in future times car sharing mobilities in Figure 3.18 has been reported the distribution.

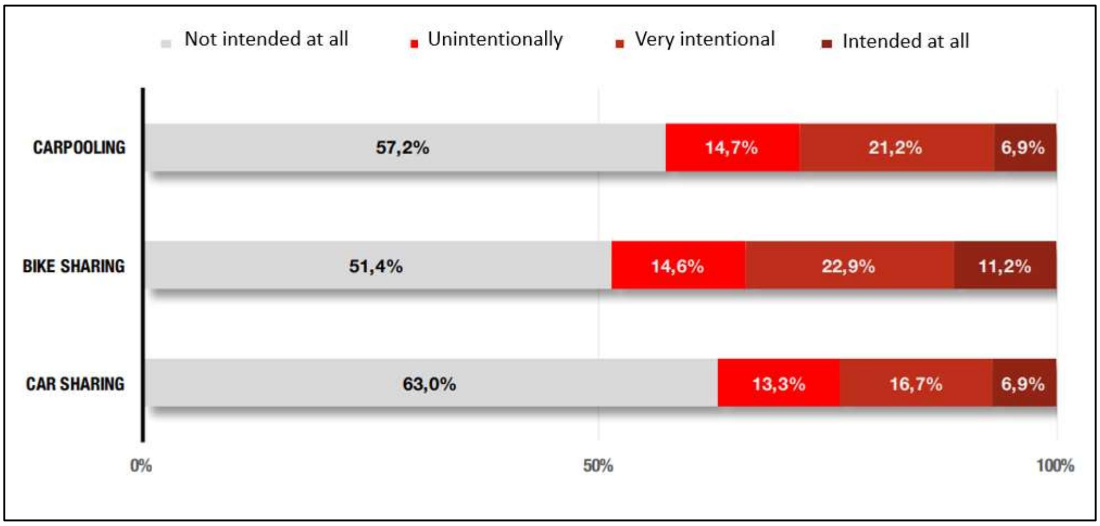


Figure 3.18. Future attitude towards sharing mobilities.

Looking at usage intentions by role, more than half of students, female collaborators and collaborators declared that they intended to use bike sharing services in the future. 24.8% of students were very willing to use bike sharing, 15.9% had little intention while 11.9% say they are fully intending to use bike sharing in the future. 25.2% of male and female collaborators were a lot intending to use these shared solutions in the future, 14.3% have little intention while about 14% is fully willing to use bike sharing.

Two professors out of 5 (38.5%) intended to use bike sharing in the future, 10.9% of professors were completely willing to use bike sharing and 15.5% are very willing. Two-thirds of TA staff (65.8%) reported that they do not intended to use this shared navigation mode in the future. 17.4% of TA personnel are very willing to use bike sharing while only 6.8% are fully willing.

From the distinction by roles, it has been seen that administrative and academic were the most resistant categories to the use of the car sharing, specifically 69.8% of administrative staff and 68.2% of professors declared that they do not intend to use it in the future to reach the University. On the contrary, 54.4% of male and female collaborators and about 40% of students declared that they intended to use this service in the future. 27.7% of collaborators and 16.8% of students declared that they are very willing to use the services of car sharing in the future.

Regarding the possibility of using carpooling services to reach the campuses, students, and collaborators appeared to be among the most intentioned, respectively 47.1% and 46.4%. About 24% of students and about 23% of collaborators declare that they were very willing to use carpooling. Academic and administrative staff remained more reluctant to use carpooling: two thirds of professors (69.2%) and two thirds of TA staff (67.8%) report that they do not intend to use this service in the future.

In general, it has been observed that precisely were the younger categories (students, female and male collaborators) who were the ones more flexible to the present and future use of shared mobility services.

A section of the questionnaire was aimed to learn about the usage habits of one's smartphone in order to obtain information or take advantage of services dedicated to mobility. In detail, respondents were asked about their frequency of using the smartphone to obtain information and services regarding the journey to be made, then paying attention to the main Apps used for mobility. In general, 23% of respondents used the smartphone every day to get information about the route to take, 35% a few times a week and 29% a few once a month. The main used app concerning mobility has been reported in Figure 3.19.

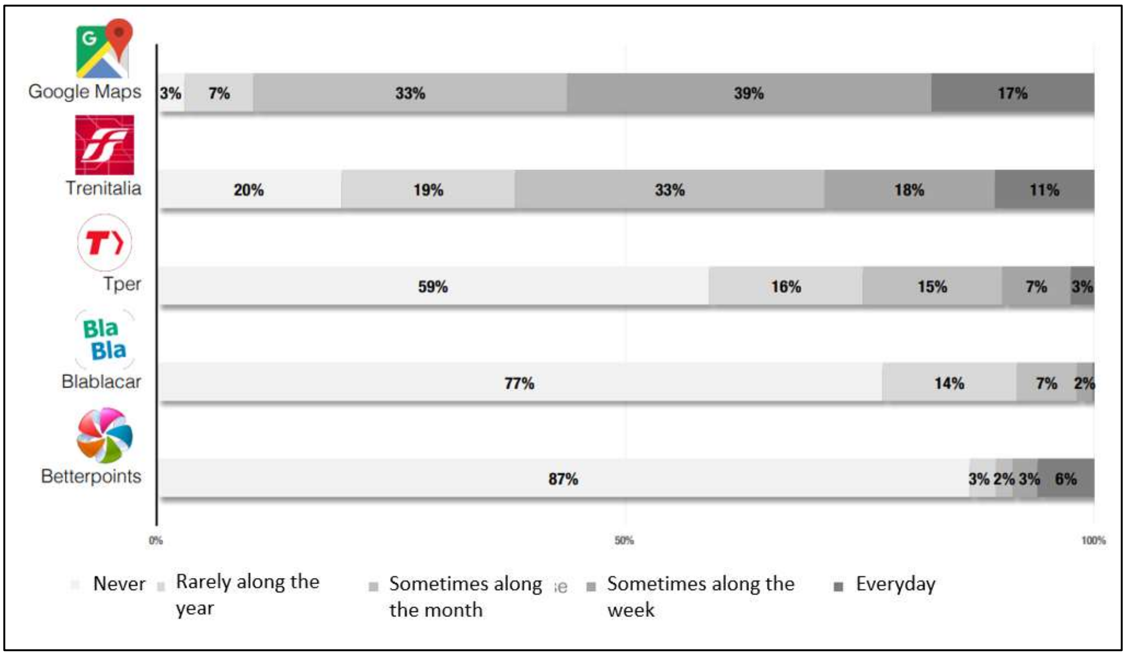


Figure 3.19. Type of mobility app frequency of usage.

Concerning capital of mobility, the possession (or not) of a potential vehicle that you can use on a daily basis for your own journeys (without exclusively considering the commuting journey), 81% of the participants declare that they had at least one bicycle, 78% own at least one car while 76% of respondents did not have a motorcycle or a scooter, as reported in Figure 3.20.

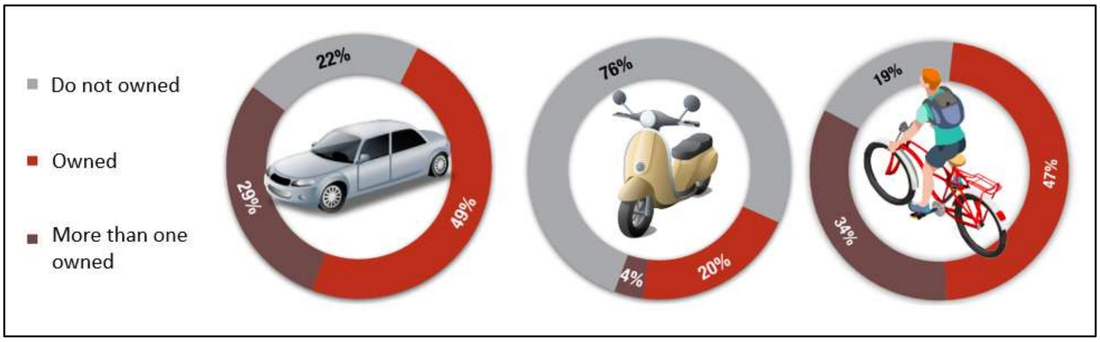


Figure 3.20. Mobility capital.

Finally, respondents were asked to indicate, on a scale from 1 to 10 (1= not at risk at all; 10= completely at risk), the perception of risk relating to the main methods of travel. From the observations of the participants it followed that the ways of moving perceived as safest were public transport and walking', with an average score of 3.5 and 4 respectively sustainable, the average perception of accident risk for cars is 6.1 and 7.5 for motorbikes/scooters. In general, the accident risk perceived by respondents is high for motorcycles/scooters, medium-high for bicycles and the car, low for public transport and for walking.

3.2.1 Statistical analysis and discussion on GOTOUNIBO 2017

The collected data were analysed using IBM SPSS 25. The aim of the research (De Angelis et al., 2020) has been to find answers to following questions:

- How do the psychological factors, situational influences, built environment characteristics, and mobility constraints influence the choice to use the car to reach the campus among university commuters?
- Are there any predictors that differ in influencing the modal choice depending on the distances to be covered?
- Are there predictors who influence the modal choice regardless of the distance to be covered?
- Do students, professors and staff adopt different commuting strategies depending on the distance to be covered to reach the university?

Prior to any statistical analysis, data cleaning and missing values analysis were conducted following the Little and Rubin's framework (Schafer et al., 2002). The Little's MCAR test was significant (v2 ¼ 271,488, df ¼ 91, p ¼ 000) revealing a potential absence of data randomly distributed (MAR). As already suggested from Osborne (2013), since patterns of missing data could be meaningful, we handled the missingness by preforming a Multiple Imputation (MI) for missing values (Garson, 2015). In recent years, this strategy has been receiving more and more attention due to the combination of complex predictive applications of multiple regressions (e.g., maximum likelihood estimation, Markov Chain Monte Carlo simulation, etc.) to estimate missing values from the information available in the existing data. As suggested by previous studies, we performed a minimum of 20 iterations (Graham et al., 2007) and including auxiliary variables (e.g., variables significantly associated with the reasons of missingness; Mustillo et al., 2015) to make the imputation robust even in an MNAR situation. Since the selected and dependent variable were not normally distributed, we performed a Bayesian regression (Muthen, 2011). Bayesian methods offer theoretical and practical advantages, as compared with the standard frequentist test (e.g., Wagenmakers et al., 2008). For example, the use of Bayesian methods results in more accurate results than the frequentist test when parameters are not normally distributed (e.g., Lee et al., 2004; Stegmueller, 2013). In this sense, Bayesian analysis estimates the lower and upper values of the credible intervals in which the actual parameter can be found for the observed data within a confidence interval level (Zyphur et al., 2013). Confidence level to estimate the credible intervals were conventionally set to 95%. Finally, by applying proportional weights to cases, stratified by role and gender (i.e., % of the stratum in a population divided by the % of the stratum in the sample), it has been possible to inflate under-sampled cases, deflate oversample cases and eventually reduce sampling error (Maletta, 2007).

The statistical analysis presented the results illustrated in Figure 3.21.

Explanatory variables: socio-demographic, situational, infrastructural and psychological variables				
Socio-demographic				
Age	Mean	*SD*		
	30	12.71		
Gender	Male	Female		
	40.9%	59.1%		
Status	Students	Professors	University staff	
	73.2%	9.1%	17.6%	
Built Environment				
Population density (inhabitants/km^2)	Mean	*SD*		
	1386	1017.65		
Share mobility service availability	Yes	No		
	22.6%	77.4%		
Situational				
	Yes	No		
Bus season ticket	37.1%	62.9%		
Train season ticket	24.8%	75.2%		
Family needs	13.3%	86.7%		
Habit discontinuity	Never	Once	Twice	More than twice
	53.6%	30.8%	9.0%	6.5%
Psychological				
	Mean	*SD*		
Past car use[a]	3.34	1.54		
Past bike use[a]	2.86	1.46		
PBC	3.20	1.33		
Personal Values	3.43	0.76		

[a]Past mobility behaviors have been included in the psychological dimension as they are considered as an indirect measure of the habit of using the means of transport, regardless of the context and nature of the trip (e.g., recreational or commuting trip).

Figure 3.21. Statistical analysis results.

The descriptive analysis of the modal share of the car within the three commuting distances, illustrated in previous paragraph, revealed that people tend to consider the car as the primary mode of transport as the length of the journey to the destination increases. Indeed, 5.8% of the commuters traveling short distances (N ¼ 94) rely on the car for their mobility needs. The share of people who adopt the car increases up to 36.3% for medium distances (N ¼ 440) and up to 54% for long journeys (N ¼ 722).

Bayesian regression means and credible intervals are shown in Figure 3.22.

	Short trip M (95% CI)	Medium trip M (95% CI)	Long trip M (95% CI)
Socio-demographic			
Age	−0.00 (−0.00; 0.00)	0.00 (−0.00; 0.00)	0.00 (−0.00; 0.00)
Gender = Male	−0.00 (−0.02; 0.02)	0.003 (−0.03; 0.04)	0.00 (−0.02; 0.03)
Status			
Students	**−0.12** (−0.18; −0.07)	**−0.18** (−0.27; −0.10)	0.01 (−0.06; 0.08)
Professors	0.03 (−0.01; 0.08)	0.03 (−0.03; 0.09)	0.03 (−0.03; 0.08)
Staff	*REF*	*REF*	*REF*
Built Environment			
Population density	**−0.00** (−0.00; −0.00)	−0.00 (−0.00; 0.00)	0.00 (−0.00; 0.00)
No share mobility services	0.01 (−0.01; 0.03)	**0.07** (0.03; 0.12)	0.02 (−0.00; 0.05)
Situational			
Bus season ticket = Any	**0.04** (0.01; 0.06)	**0.22** (0.18; 0.25)	**0.24** (0.21; 0.27)
Train season ticket = Any	−0.01 (−0.08: 0.07)	**0.22** (0.17; 0.27)	**0.27** (0.24; 0.30)
Family needs = Any	**−0.06** (−0.09; −0.03)	**−0.05** (−0.09; −0.00)	−0.03 (−0.07; 0.01)
Habit discontinuity			
Never	0.02 (−0.02; 0.06)	−0.00 (−0.08; 0.08)	−0.06 (−0.13; 0.02)
Once	−0.00 (−0.04; 0.03)	0.04 (−0.04; 0.12)	−0.05 (−0.12; 0.03)
Twice	−0.01 (−0.05; 0.03)	0.02 (−0.08; 0.13)	**−0.12** (−0.21; −0.03)
<2	*REF*[d]	*REF*	*REF*
Psychosocial			
Habitual car use	**0.02** (0.01; 0.03)	**0.06** (0.04; 0.07)	**0.01** (0.00; 0.03)
Habitual bike use	**−0.01** (−0.01; −0.00)	**−0.02** (−0.04; −0.01)	**−0.01** (−0.02; −0.00)
PBC	**−0.05** (−0.06; −0.04)	**−0.10** (−0.11; −0.08)	**−0.07** (−0.09; −0.06)
Personal Values	**−0.02** (−0.04; −0.01)	**−0.03** (−0.05; −0.00)	−0.00 (−0.02; 0.01)

Note: Confidence level was conventionally set to 95%, Values in bold are statistically significant
REF: it represents the level of the ordinal/nominal variable selected as reference for the analysis

Figure 3.22. Bayesian regression means, and credible intervals based on commuting distances.

The analysis on exploring the key determinants for differences and impact changes of car use depending on the distance to cover to reach the campus, specifically for short (38.2%), medium (29.3%) and long (32.5%) commuting distances. Following the suggestion given by Whalen et al. (2013), the primary purpose was to explore and identify the factors that affect and vary car use choice by comparing distances to Campus. The type of dimensions included in the analysis differently explained the variance for short, medium and long commuting trip. Explicitly, the variables combined explained the 27% of the variance for commuting trips made within 5 km, the 54% for medium commuting trips and the 47% of variance for commuting trips longer than 30 km. The results suggest that students are more likely than professors and university staff to use a sustainable mode of transport than the car for a short and medium commuting trip whereas for long commuting distances, socio-demographic characteristics do not seem to affect the modal choice.

In terms of built environmental characteristic, starting from a place with higher population density appears to reduce the use of the car only for short distances (<5 km).

In contrast, the presence of any sort of shared mobility service (e.g., car sharing) facilitates a reduction of private car use only within distances between 5 km and 30 km.

Considering the role of situational factors, not having a bus season ticket is likely to prompt the use of the car at any distance to the final destination. Similarly, not having a train ticket season is likely to prompt the use of the car only for medium and long commuting trips. The lack of family needs, instead, leads to a decrease in the likelihood to use the car for short and medium distances. Furthermore, considering the habit discontinuity hypothesis, participants who had experienced more than one change of residence or relocation during the previous five years were more willing to reduce the use of the car only for their long commuting trips. Concerning habitual mode use behaviors, being used to driving is likely to facilitate the use of the car for one's own commuting trip, whereas being used to cycling is likely to reduce the use of the car, regardless the length of the journey. Finally, exhibiting a personal inclination to choose a different means of transport than the car is likely to reduce the use of commuting by car. Personal values in favour of a sustainable mode of transport did not show any significant effect on the car choice only for long commuting trip.

At first glance, it is noteworthy that the effect of some variables is significant regardless of the distances to be covered. Secondly, a very intriguing aspect is the variance explained by the combination of the variables introduced in the analysis. The results clearly show that for short distances, in particular those involving inner-city routes, there should be other factors influencing one's modal choice. For example, as suggested by Zhou (2012), the chosen area of residence could already explain much more variance of the variables included in the study. Alternatively, personal attitudes and perceptions with respect to the different means of travel can have a crucial role in shaping modal choice decision for short distances (De Witte et al., 2013).

The results provide support for a recent trend concerning the younger generation (Delbosc et al., 2013; Kuhnimhof et al., 2012), that students are those more willing to use other modes of transport than the car for their commuting trip, in particular, for short and medium trips. As stated by Prillwitz and Barr (Prillwitz et al., 2011), the younger participants can be considered as “green travellers,” even though we were unable to explore the reason behind it. A plausible explanation can be related to participants’ income, thus suggesting that professors and university staff are more likely to own a private car than students because they generally have a higher income (Chen et al., 2008; Zhao, 2013).

Second, similar to previous studies (Kim et al., 2008; Whalen et al., 2013), the results suggest that the presence of children or the responsibility to take care of elderly relatives and people with disabilities influenced people’s choice in favour of private car use. However, the effect was significant only for short and medium trips. In other words, when the distance to cover is considerable, people seem forced to organize their daily activities accordingly, regardless of the presence of family needs and they are thus more susceptible to car use. Anable and Gatersleben (Anable et al., 2005), when considering work journeys, pointed out that car use is more attractive because of its convenience (e.g., degree of autonomy). Hence, for trips that do not entail covering a large number of km, people with family needs prefer to use the car for its flexibility. These aspects should be further explored in future studies trying to highlight in which way the need to stop along one’s route to meet personal needs (i.e., family needs) influences the choice of means of transport and, at the same time, to understand which aspects and characteristics of the various means of transport available best meet these needs.

Apparently, without the perception of a lower cost to start adopting or maintaining a different style of commuting behavior than the car, the person finds a modal shift problematic. This challenge is further amplified if the person exhibits a strong habit in driving (de Kruijf et al., 2018).

Third, it has been explored the role of the population density. Even though the effect of this built environment characteristic can appear to be small, we found that people who live in highly populated area are more willing to use an alternative mode of transport instead of the car, which is in line with the previous findings (Chen et al., 2008; Kim et al., 2008; Santos et al., 2013; Zhao, 2013). In other words, living in a highly populated area can facilitate the use of sustainable mode of transport if people can easily reach their destination by more relaxing or pleasant mode of transport than by car within short distance. Policy and interventions should consider the role of built environment influences on modal choice (e.g., street density and sidewalk density) in order to meet the needs of users who prefer not to use the car for their short trip.

Fourth, in line with previous research, our results support the notion that people who are used to driving in their daily routine, are more willing to use the car in their commuting trips as well, irrespective of the distance to cover. This aspect has been confirmed when controlling for the status category. On the contrary, habitual bike use is affecting car use, and people who cycle regularly are more willing to use alternative modes of transport to their car. Probably having experienced the positive effect of such sustainable and active mode of transport (Thomas et al., 2015) affects people's mode choice for commuting trips in a "greener way". Additionally, as suggested by de Kruijf et al. (2018), people who are used to take alternative modes of transport than car (i.e., bicycle) may be more open to travel options in their commuting trip. In the end, what is worth noting is that a past positive modal experience, changed into a habitual process, has become an automatic decision-making process that can influence our choice of modal commuting, regardless of the distances to travel. In other words, for those who are used to driving a car, it may be challenging to make a modal shift, unless a disruptive event occurs as suggested by the habit discontinuity hypothesis.

In these terms, the COVID-19 has represented a disruptive event, which effects has been discussed in paragraph 3.2.

3.3 Post pandemic context modalshare

More recently, in 2021 a similar online survey, named PASSACOLVERDE, has been conducted to evaluate how the mobility habits may undergone a change after 2020 pandemic impacts. It has been submitted similarly to GOTOUNIBO, but it has been used an institutional web platform to support the web questionnaire. At the end of the surveys, 7,300 people decided to join by completing the questionnaire.

The survey analysed mainly academic and administrative staff and students' choices, avoiding the collaborators, which categories has been progressively reduced from 2017 till 2021, for normative reason and now it represents a no more relevant categories, representing less than 1% of the entire administrative staff.

Almost variables investigated are completely compliant and in accordance with GOTOUNIBO evaluation. Consequently in this Thesis has been shortly showed only modalshare results.

The survey asked if and how the previous mobility choices has been confirmed or less after COVID-19 impacts. In figures 3.23, 3.24 and 3.25, are illustrated modal share, in terms of main transportation mean, adopted by each university category after pandemic.

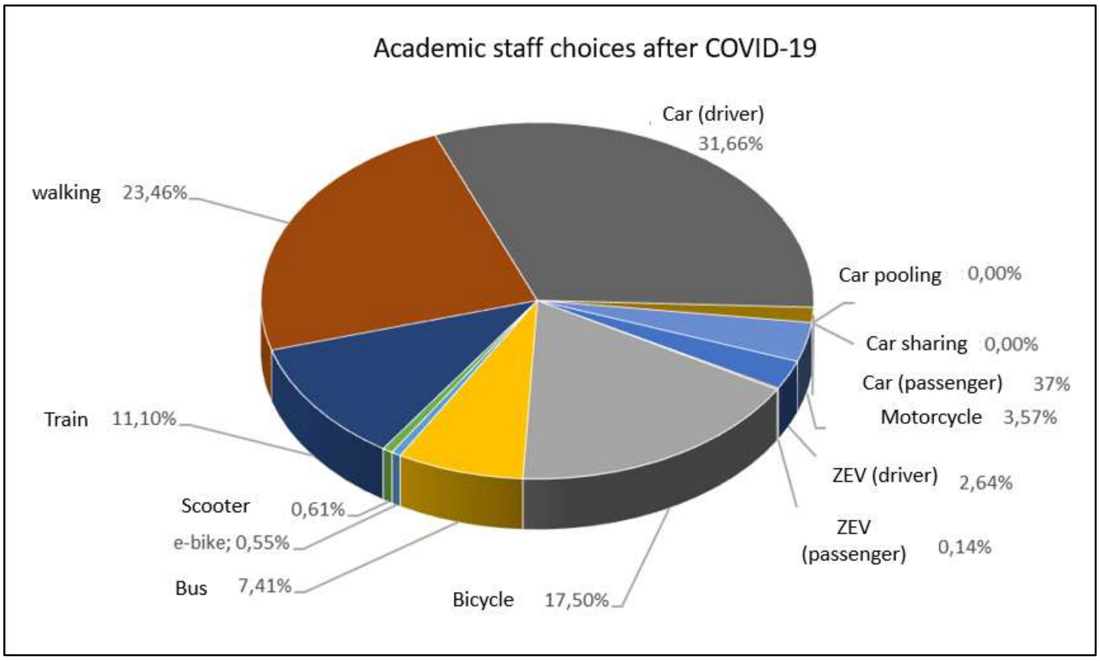


Figure 3.23. Academic staff modal share after COVID-19.

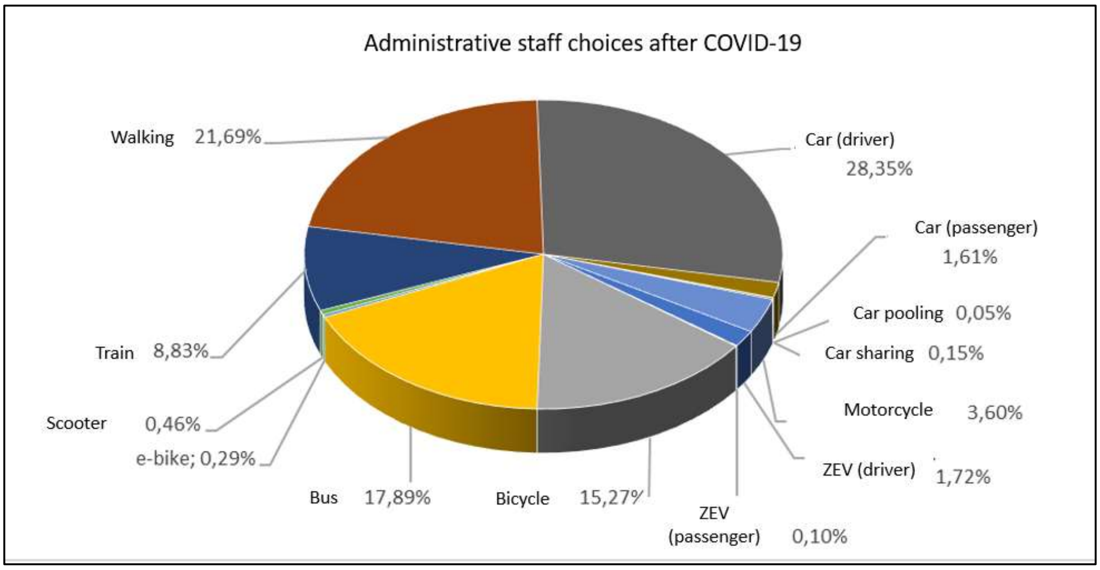


Figure 3.24. Administrative staff modal share after COVID-19.

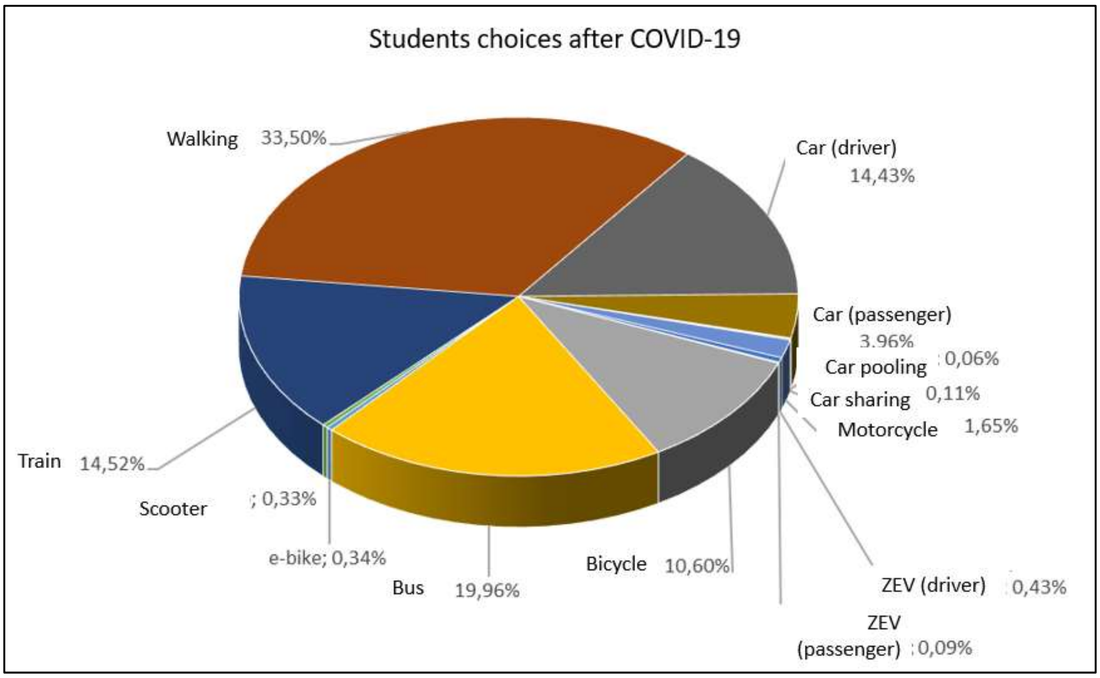


Figure 3.25. Students modal share after COVID-19.

Regarding the modalshare in general terms, it has been detected a reduction in train use, an increase of bicycling use in academic and administrative staff, on contrary of student tendency about cycling that registered a reduction, an increase in car use in all the categories, while sharing mobility does not register a relevant changing. Bus seems to have a reduction, strongly in employees and less relevant in students.

The reduction on cycling emerged by students participants should be associated with the fact that lesson in presence, in spring 2021 has not been still fully reactivated.

However it is interesting to underline how impact of COVID-19 seems to have impacted in increasing preferences in not collective transportation means, with a recurring major use in individual means, probably associated with sort of fear of contagion related to proximity conditions during the trips.

Chapter 4. Almabike project storytelling

4.1. Goals and origin

Almabike is a holistic project, in terms that it comprehends different goals and measures within. First it is placed into the general framework of actions aimed to enhance cycling among students. Indeed in 2016 the Municipality of Bologna has proposed to the University of Bologna the availability of a specific funds, allocated by the Environment Ministry on air quality issue to local governance. In 2016 there was not a strong and wide spread bike sharing public service in Bologna, so the initial propose for Almabike was to define an innovative project based upon bicycles given to students, granted them for free, able to create a cycle fleet for home-campus trips, integrated by air quality sensors.

The main goals may be described in general terms as:

- A Mobility management measure to enhance cycling.
- A crowd sourcing research project to improve healthy streets approaches.

The specific goals are:

- to offer a pilot bike service reserved to university students, aimed to respond to home-work commuting;
- to enhance the key role of cycling into university community;
- to create an original designed city trek bicycle, branded by University copyright, able to enforce the sense of identity among university community, in particular students;
- to experiment a two-wheels environmental laboratory, able to detect particulates and others environmental parameters in function of the lanes' exposure.

The availability of the funds was strictly limited under the following conditions: free charge uses, availability for 500 or more students and rotation of the 500 bicycles among several students, in order to extend the total number of beneficiaries.

First approach to the project by University of Bologna has been to design the model of bicycles. Consequently it has been settled up a competition of ideas, open to the entire community of students, to give shape to the project of a bicycle as an identifying object of the University of Bologna's image and which at the same time satisfies the characteristics of technical functionality, quality technology, durability and comfort. The Contest responded to the need to satisfy the sustainable mobility needs of students who use the bicycle for urban home-study-leisure travel, since it is a broad-spectrum sustainable means of transport: healthy, silent, ecological, economical, not cumbersome and fast. The call conditions have been that the winning project would has been presented to the industrial company that the University appointed to produce the bicycles, and a model would has provided free of charge to the winner author of the project, as price.

For the elaboration of the project proposal, the following specifications of the bicycle have been provided:

- be configured as a model: man, woman or unisex;
- be a City-bike;
- be equipped with a gearbox (there are no restrictions on the type chosen);
- be equipped with traditional wheels of 26", excluding wheels for racing bikes;
- be equipped with front and rear mudguards;
- light frame (there are no constraints on the material).

Each project proposal, identified with a name/motto, had to be presented using the following graphics terms:

- n. 1 A1 format table, able to give overall full visibility and understanding of the shape and look of the bicycle and which contains:

a) 1 side view

b) 2 views of the front and back

c) 1 top view

d) Render at will

- n. 3 A2 format tables of construction details including:

a) handlebar details (handlebar, stem/stem, grips, steerer tube and levers);

b) details of the transmission (crankcase, chainring, pedals and crank) and of the front and rear derailment system (front and rear derailleur);

c) seat details (saddle, saddle frame, saddle clamp, seat post.

The construction details had to be complete with dimensions and measurements such as to make the dimensions of the components and the complex dimensions of the assembled parts understandable and be able to produce an industrialize and model.

The call received only 3 proposes, respectively illustrated in Figures from 41. to 4.10.

Figure 4.1. Almabike propose #1: frontal lateral and upper views.

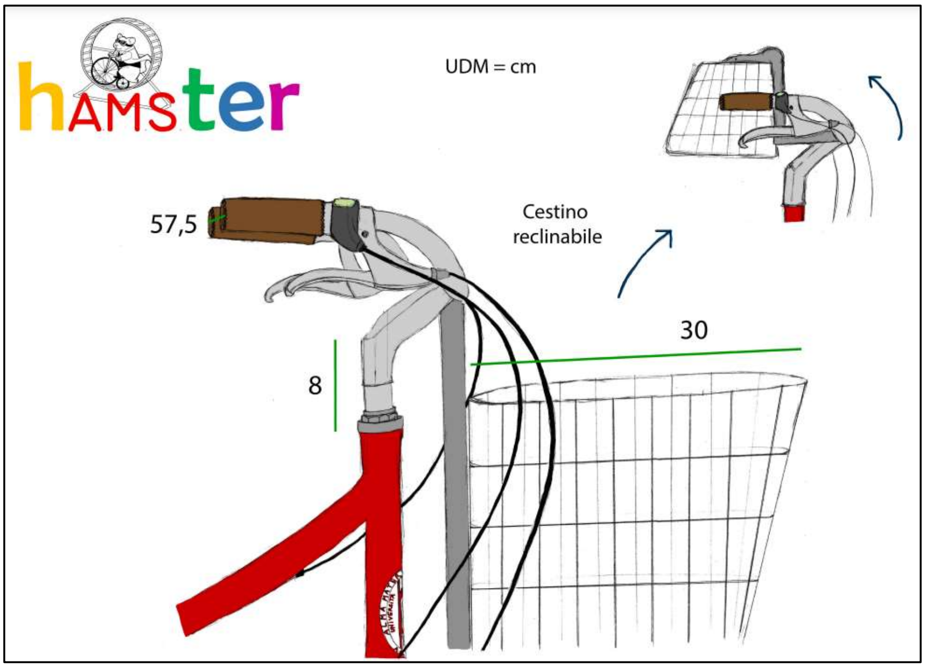


Figure 4.2. Almabike propose#1: basket details.

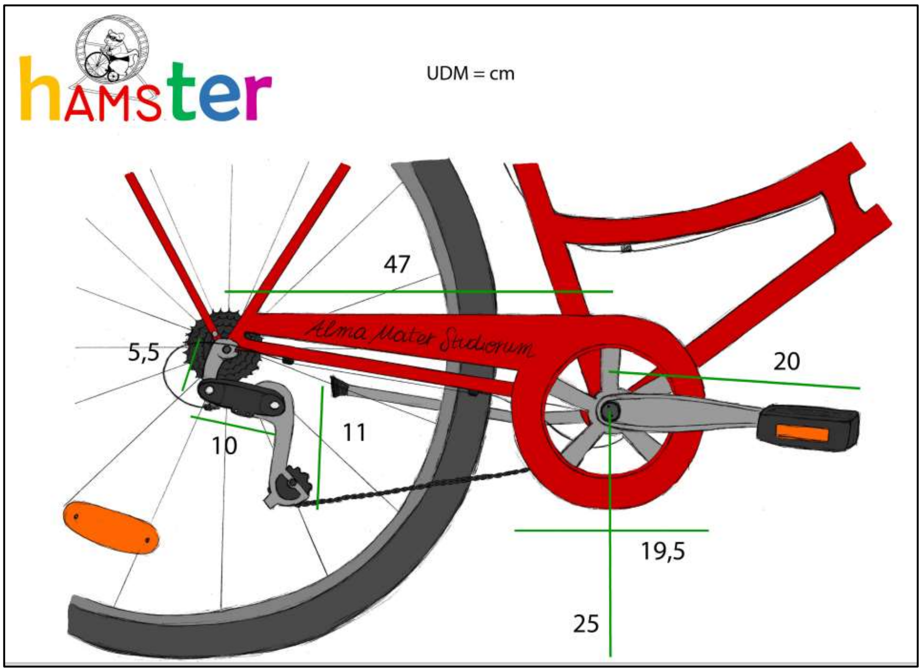


Figure 4.3. Almabike propose#1: transmission.

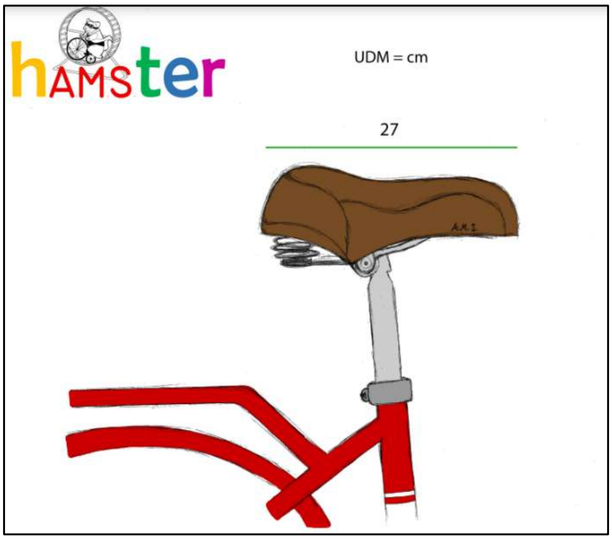


Figure 4.4. Almabike propose#1: seat detail.

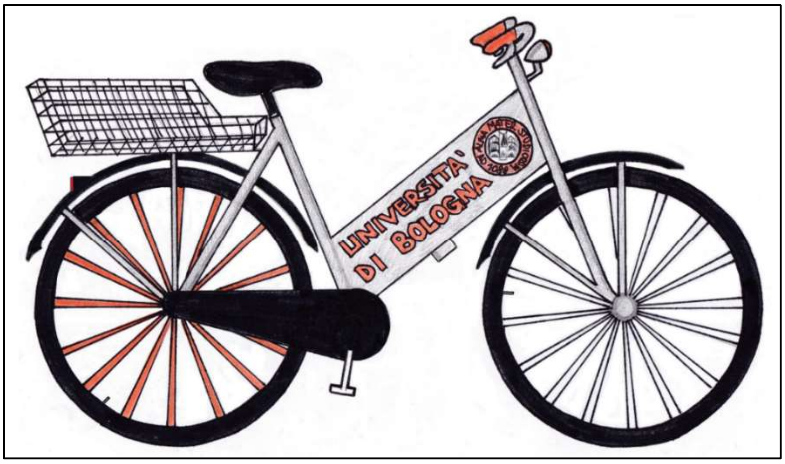


Figure 4.5. Almabike propose#2: general overview (e-bike)

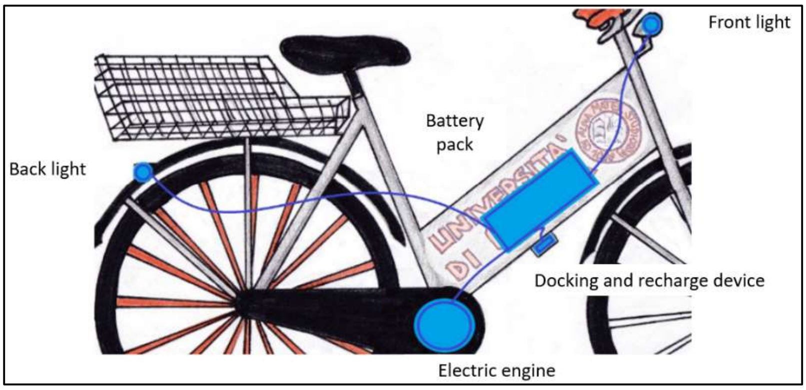


Figure 4.6. Almabike propose#2: electric engine.

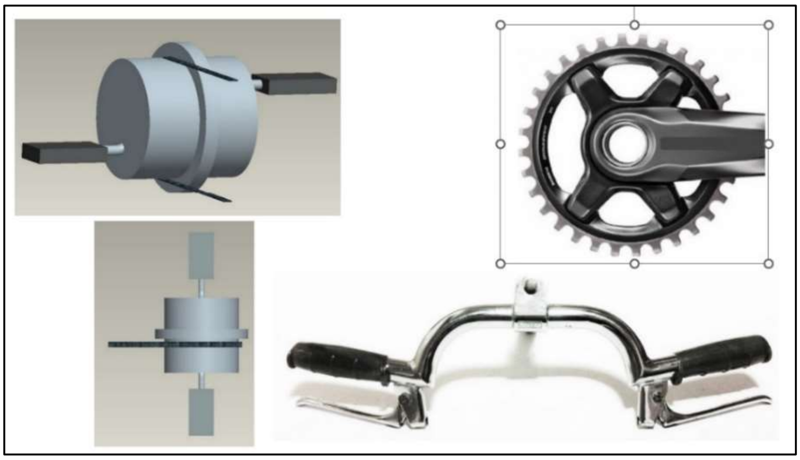


Figure 4.7. Almabike propose#2: details.

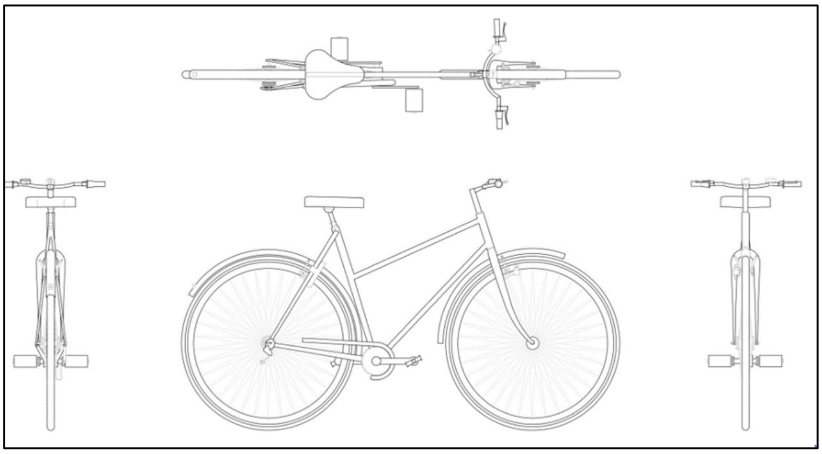


Figure 4.8. Almabike propose#3: general overview.

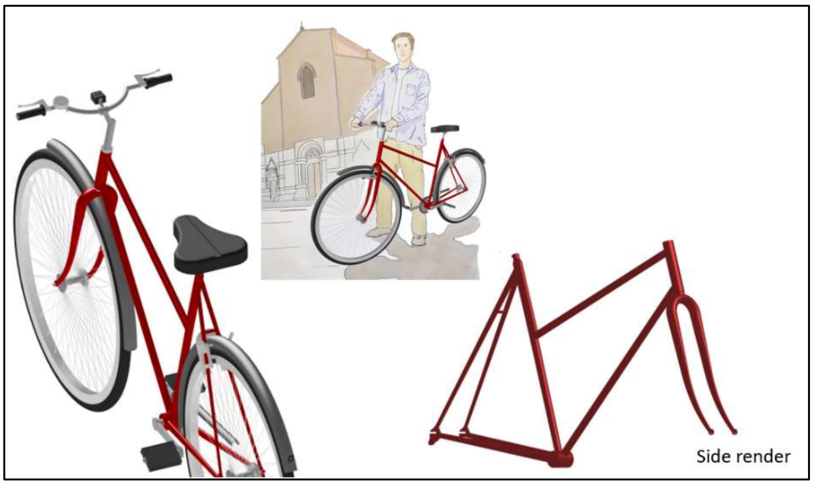


Figure 4.9. Almabike propose#3: renders.

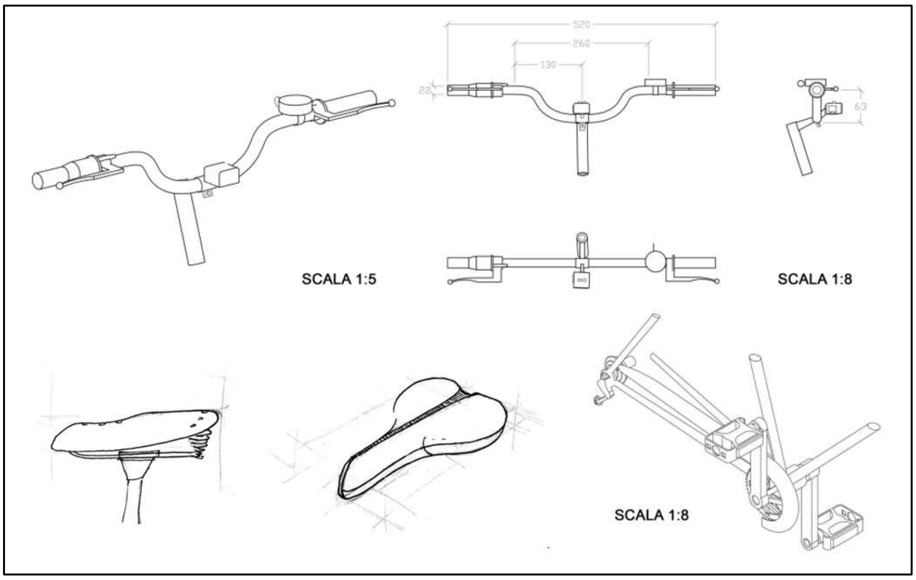


Figure 4.10. Almabike propose#3: details.

The Call Commission has established the following evaluation criteria:

- innovation and originality of design (40/100 points);
- technical and construction feasibility of the project (30/100 points);
- ability to enhance the University's identity (30/100 points).

On the basis of the defined criteria, the Propose#2 has been considered out of target, due to the fact that it proposed an electric bicycle (e-bike) with pedal assist, and the winner project, that reached the highest score, has resulted the propose#3.

4.2 From design to production phases

In 2018 a first technical committee has been established, leaded by the mobility manager and comprehending external cycle engineer, with the aim to verify the winner project technical details in order to start up the massive production. The committee has found some critical issue mainly in the frame, that presented a point of weakness, as illustrated in Figure 4.11.

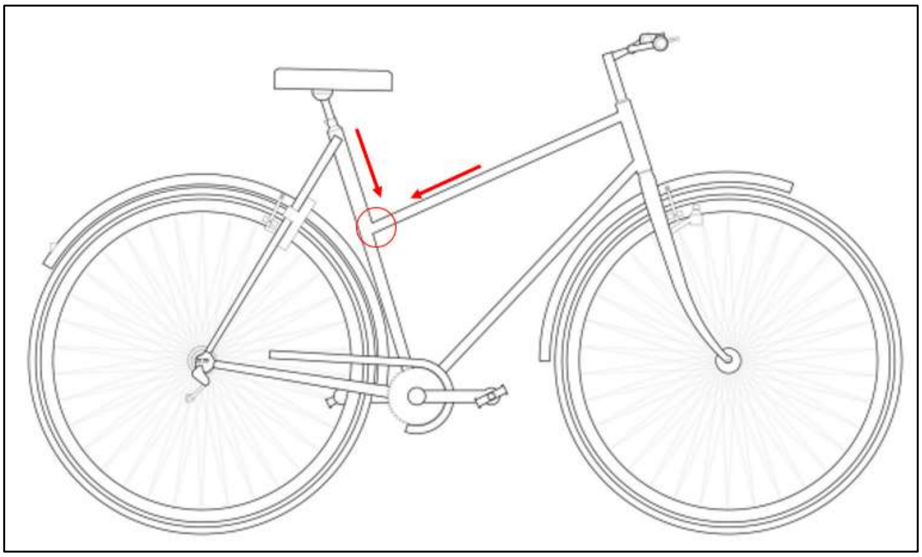


Figure 4.11. Almabike structure critical problem.

On the basis of the need to re-engineering the design University of Bologna, with the aim to assure a more stable frame, has selected a professional designer: Jonny Mole s.r.l. The company selected, with expertise in brand communication and bike design, has approached the Almabike project, with the aim to find a new look and feel for the bicycles, given more attractiveness and a distinct original design. The frame has been revisited as well as the wheels that passed to 28”. The bicycles have been empowered by technological solutions as GPS tracker (with also Bluetooth connection option and integrated data transmission SIM), and a battery pack able to grant energy to accessories and devices only, not acting as pedal assist. The solution is illustrated in Figures 4.12 – 4.15.

Figures 4.12. Almabike re-designed front perspective.

Figure 4.13. Almabike re-designed back perspective.

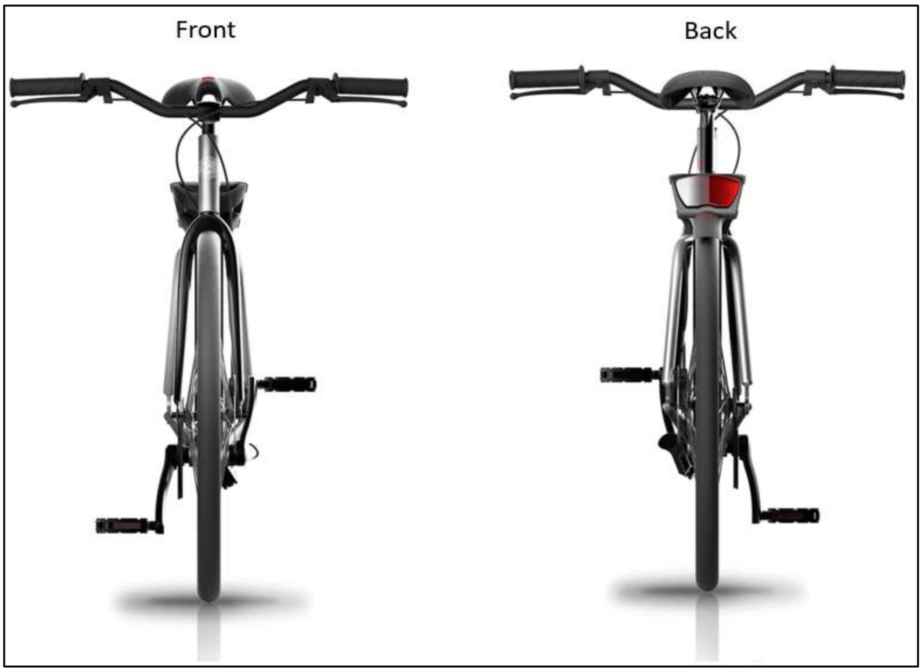


Figure 4.14. Almabike re-designed front and back view.

Figure 4.15. Almabike re-designed side view.

As clearly indicated in Figure 4.12 and 4.15 the bike presented a sort of battery pack in the back rack. It has been designed with the aim to grant energy to sensors, that represented a second and separate project and provision, described in chapter 4.2. As just defined the ultimate design, University of Bologna started up the process to select industrial developer and provider. First, it has been submitted the bike design to Brand office of University in order to copyrighted the intellectual product. After some month of market analysis, it has been confirmed the originality of design and use of the brand. Consequently use of Almabike image and brand has gone under license. Second, it has been engaged in parallel the Procurement Office, in order to evaluate the possible risk of normative interferences to the purchase/production procedures. In late 2019 it has been possible to define the public selection. The reason for the delay has been mainly in the market analysis underlined the purchase procedure, splitted in two main issues. In appearance the provision seemed to conflict with existing bike sharing service (also in Electronic Purchase market for Italian public administration – MEPA), as well as the difficult to find a provider able to grant a wide furniture in few months. University had further investigated and finally defined in legal terms how the concept of traditional bike sharing should not be applied in this case, in which bicycles were granted for a long term to singular students, on contrary of a bike sharing, in which the bicycles could change for each trip.

Secondarily the market analysis reached out the interests of only few bicycles productors, due to the huge production, but some suggestions has been however detected. Among them the most relevant, by a point of view of further project development, has been the need to reduce the overall production impact, driven by the presence of the battery pack and technology devices. The main reason is that the technical particulars introduced an electric-mechanics complication, not easily granted by bicycles productors, that act basically as mechanic assembler than technologic partner.

Consequently it has been possible to public the provider selection in November 2020. This procedure had as object the furniture of 650 bicycles, in which 600 were destined to students use and 50 specifically oriented to environmental research. The auction overall amount has been defined in 208,000€ for the entire provision, on the basis of single bike basis cost of 320€, tax value excluded.

Mandatory characteristics requested within the public selection has been illustrated in Table 4.1.

Elements	**Requirements**
Concept	The alma Bike is conceived as a unisex "city bike", with a sporty design. The bicycle must be characterized by an original design and possess the technical requirements of reliability/practicality, simple maintenance, durability over time and lightness.
Materials	The materials used must have the characteristic of resistance to atmospheric agents, lightness and ecology, favouring recyclable materials. The materials must also be free in each of their subsets of toxic components in compliance with current legislation, such as, by way of example but not limited to: asbestos, ozone, PFC (polyfluorocarbons), PCB (polycarburovinyl), CFC (chlorofluorocarbons). In the construction of the vehicles, the requirements of protection against fire must be kept in mind as well as the use of non-flammable, self-extinguishing or low flame propagation materials.
Chassis	The frame must have a size of the Medium type, suitable for a user of average height of 1.75m, with a front swing of 100mm and a rear swing of 130mm. The frame material is strictly aluminium. The top tube, down tube, and seat tube sections do not represent a prescriptive geometry shape. Front and rear dropout shown in the drawing are not binding in terms of measurements, but constitute an invariant in terms of shape.
Transmission	The transmission can be chain or belt. These elements constitute evaluation factors during the tender.
Wheels	Both wheels must be 28 inches (700mm). The rims must have compatible dimensions for urban use and must have a low profile (height around 2cm). The width of the rim indicated in the graphic is indicative and can be changed. The wheels must not have a quick release system, with bolts preferably hexagonal or with a gravitational anti-theft system. Front and rear mudguards are expected with lightness characteristics, in plastic material and wheel cover capable of adequately protecting the cyclist. The supports of the mudguards relate to special predispositions on the frame.
Tires and inner tubes	The characteristics of the tire must be such as to present suitability for urban routes, with a non-smooth tread, therefore with adequate grooves to facilitate movement on city road surfaces.

	The tire can be in size between 32-622 and 37-622 ETRTO The tire must have characteristic aesthetic elements.
Breaking system	A hydraulic disc braking system with 160 mm diameter discs or a mechanical disc braking system is envisaged. These elements constitute evaluation factors during the tender.
Gearbox and transmission	The gearbox is placed in the rear hub, the transmission is by belt. There must be a light crankcase capable of covering the crankset (crank/chainring system) and most of the upper chain path. Completely closed transmission guards are excluded, in order to facilitate easier maintenance.
Saddle	The saddle must be ergonomically comfortable and waterproof, which does not cause obstacles when pedalling. The saddle post fixing system must not allow a quick release and the saddle post itself must be fixed to the frame with the relative bolt, in order to discourage theft.
Handlebar	The aesthetics and dimensions of the handlebar indicated in the drawings are not binding. It must be equipped with characteristics such as to allow the balance of position comfort with steering stability. The handlebar height must be adjustable. Handlebar features: ergonomic grips, bell, gear lever.
Pedals	The pedals must not be hooked to the shoe, be simple and equipped with a reflector system. The materials are at the discretion of the supplier. Crank length: 165mm
Lights	The use of magnetic lights is foreseen.
Accessories	Side stand and reflectors in the wheels (one on each side for each wheel).

Table 4.1. Mandatory requirements for Almabike components.

On the basis of the drawings of the minimum technical characteristics of the supply contained in the specifications, the bidder should have to deliver a descriptive report accompanied by figures of the Almabike model intended to produce.

The documentation provided by the participants, had to allow the University to evaluate the design, morphological and aesthetic solutions of the proposed bicycle.

A list of key components, attached to the public selection, is reported in Table 4.2.

Aluminium frame, painted steel fork
700x35 front and rear tyre
28" front and rear wheels
Aluminium front hub
Aluminium rear hub with 3-speed gearbox
Front and rear hydraulic disc brake system
Adjustable stem + handlebar + grips
Tripod in black anodized aluminium
Brake levers
Custom saddle
Ergonomic seat
Magnetic lights
Front and rear mudguard
Quill
Saddle locking with collar
Pedals with integrated reflector
Bluetooth tracker system, USB rechargeable

Table 4.2. Almabike main component list.

The selection has presented only one company participant that declared that it was not possible to provide in the same furniture: Bluetooth tracker/USB rechargeable components, as well as magnetic lights.

The productor in January 2020 has indicated the following requirements attended: the bicycle is made using materials resistant to atmospheric agents, light (total weight 14 kg) without each of their subset of toxic components (such as asbestos, ozone, PFC (polyfluorocarbons), PCB (polycarbon vinyl), CFC (chlorofluorocarbons), mechanical front and rear disc brakes (disc diameter 160mm), gearbox fixed to the rear of the black Shimano Torney 7-speed frame, transmission with brown x 7 speed chain, Mixed covers

700x40 Anti-puncture black reflex. The proposal model has showed in Figures 4.16 – 4.19.

Figure 4.16. Almabike proposed prototype overall view (early 2020).

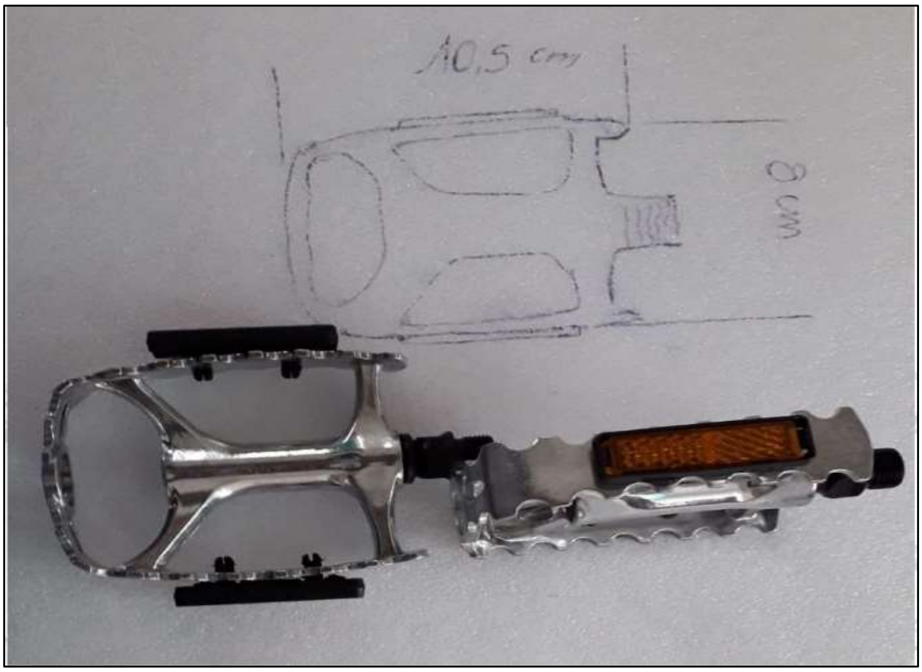


Figure 4.17. Almabike proposed prototype pedal detail offered (early 2020).

Figure 4.18. Almabike proposed prototype brand and graphic.

On the basis of that prototype presented, a co-design phase in partnership between university and productor was started, in which the model has been aesthetically revised, arriving at the definitive solution presented in the figure 4.19.

Figure 4.19. Almabike definitive model.

In February 2020 pandemic spreaded out, impacting on both university and productor conditions. Social distance and spatial restrictions forced organizations to re-think standards and activities, including results timing and operations accomplishment. The production line of Almabike has been however assured as well as possible, compatible with the disastrous logistic chain collapse, and finally between march and June 2020 the provision of 650 bicycles has been completed.

Absence of GPS trackers within the furniture and recharge systems forced university to publish another further public selection aimed to obtain the GPS tracker provision. In altered times as 2020, with export literally suppressed for technology, it has been possible only to acquire 650 low cost GPS trackers, manufactured in Italy. The furniture ended in November 2020, permitted to install GPS tracker in the bicycle frame under the seat, and have full access to a web platform to register users and track down their movements with a low accuracy, as it is described in next chapters.

Further, the web platform offered to users the opportunity to gain a security control system, in which during the bike stop phase, it was possible to activate a warning system and to receive alert mail in case of unauthorized movements of the mean, granting an approximately anti-theft device.

In addition, even to prevent or reduce theft phenomena, each bicycle reported a serial number, printed in the frame, permitting to track down the bikes once stolen. This simple approach indeed permitted to police force to find some stolen bikes during the experimentation.

4.3 Sensors

4.3.1. A brief introduction to low cost sensors

In parallel to production phases, University in early months of 2020 started the research project. The first issue has been to make a market analysis for low cost sensors able to detect environmental parameters and particles pollutants.

The main problem to solve was to have that detection capacity in small space, just to have a full integration aboard the bicycles. The solution has been found in the integration of existing sensors. Traditionally, air pollution is monitored by measuring concentrations of various pollutants such as carbon monoxide (CO), ozone (O3), nitrogen dioxide (NO2), sulphur dioxide (SO2), and particulate matter (PM) at fixed sites by using accurate and expensive instrumentation (Kumar et al., 2014). Monitoring sites in the EU are determined based on the EU Air Quality Directive 2008/50/EC, which clearly defines the minimum number of fixed monitoring stations for each target pollutant based on the air pollution levels, population, and coverage area. Such sites are generally spread in and around cities and provide temporal concentrations (typically hourly) of different pollutants. Cities in developed countries might contain one official monitoring station covering about 100,000 people as opposed to covering millions of people in cities of developing and highly polluted countries.

Recent advancements in the field of sensors, digital electronics, and wireless communication technology have led to the emergence of a new paradigm for air pollution monitoring (Hagler et al., 2013, Kumar et al., 2015). This paradigm aims to gather high-resolution spatiotemporal air pollution data by using a ubiquitous network of low-cost sensors for monitoring real-time concentrations of different air pollutants, which can be then utilised for a variety of air pollution management tasks such as:

1. supplementing conventional air pollution monitoring;
2. improving the link between pollutant exposure and human health;
3. emergency response management, hazardous leak detection, and source compliance monitoring;

4. increasing community's awareness and engagement towards air quality issues.

Though there is no universally agreed definition of a “low-cost” sensor, anything costing less than the instrumentation cost required for demonstrating compliance with the air quality regulations can be termed as low-cost. However, the cost should be as low as possible to achieve the above-mentioned aims of a sensor-based system for monitoring air pollution, so that widespread deployment is commercially feasible. The higher cost of sensing kits is expected since they typically include one or more sensors, microprocessor, data-logger, memory card, battery, and display (Rei et al., 2017). Williams (Williams et al., 2014) provided guidelines regarding sensor selection but these guidelines are open ended and leave it for end-users to carefully review a sensor's performance before purchasing it.

Low cost sensors used for monitoring particulate matters are based upon light scattering method. The reason for the uses of that method in low-cost PM sensors has related to the fact than sensors based on this principle are cheap to manufacture, have low power requirements, and quick response times (Wang et al., 2015). In this method, a light source illuminates the particles, and then the scattered light from the particles is measured by a photometer. For particles with diameters greater than ~ 0.3 µm, the amount of light scattered is roughly proportional to their mass/number concentration; however, particles smaller than ~ 0.3 µm in diameter do not scatter enough light, and cannot be detected by this method (Koehler and Peters, 2015, Thomas and Gebhart, 1994). The detectable particles (> 0.3 µm in diameter) can be size-segregated by either using an algorithm on the signal obtained from the scattered light (Northcross et al., 2013) or by attaching an impactor/filter at the inlet (Sousan et al., 2016b).

The light scattering method is used in low-cost PM sensors since the sensors based on this principle are cheap to manufacture, have low power requirements, and quick response times (Wang et al., 2015). In this method, a light source illuminates the particles, and then the scattered light from the particles is measured by a photometer. For particles with diameters greater than ~ 0.3 µm, the amount of light scattered is roughly proportional to their mass/number concentration; however, particles smaller than ~ 0.3 µm in diameter do not scatter enough light and cannot be detected by this method (Koehler and Peters, 2015, Thomas and Geb-hart, 1994).

As suggested by Rai (2017), to implement a large-scale sensor network and to use all data generated in a meaningful way, it is necessary to formulate standard guidelines to evaluate its performance in the short and long terms. The main problems are related to: calibration, stability, measurements in the field, interferences between gas and influence of temperature and relative humidity. De Nicola (2018) has been reported the results of the tests carried out with the updated version of Smart Citizen Kits (SCK). SCKs are assemblages of LCSs that measure temperature, relative humidity, noise, light, NO2 and CO concentrations. In order to evaluate their performance in the field, the sensors are tested in real conditions in the city of Bologna during the winter (February 2018) and the summer (August-September 2017) as part of two extensive experimental campaigns. The repeatability of the sensors and the reproducibility are discussed under different meteorological conditions allowing us to formulate some guidelines for their implementation. On the basis of De Nicola research, a confrontation with this research team, headed by Department of Physics of University of Bologna, has been started up. The confrontation permitted to take in consideration SCK sensors and orient to establish a contact with Fablab Barcelona, an innovation centre, spin-off of public University of Barcelona.

A series of online meeting followed, then a scientific cooperation with the research branch of FabLab has been established with the aim to realized and improve the suitable solutions for dynamic pollutants detection through Almabikes.

4.3.2 Sensors solution and production

The research conducted in partnership with Fablab Barcelona has been settled on:

- studying and allocating the sensors integration;

- defining data communications systems of sensors;
- finding compact and micronized dimension for overall sensor pack;
- studying the shape and technical characteristics of settlebag, container of the sensor pack.

The Smart Citizen Kit (SCK) is the core of what is internationally recognized as the Smart Citizen System: a complete set of modular hardware components aiming to provide tools for environmental monitoring, ranging from citizen science and educational activities to more advanced scientific research.

The system is designed in an extendable way, with a central data logger (the Data Board) with network connectivity to which the different components are branched. The system is based on the principle of reproducibility, also integrating non-hardware components such as a dedicated Storage platform and a Sensor analysis framework. First, the data board is a data-logger at the core of the sensor's architecture supporting the Smart Citizen Kit and the Smart Citizen Station. This module is powered by an ARM M0+ 32-bits 48Mhz SAMD21 running the Smart Citizen Firmware, combining the low power consumption of the ARM M0 family with the power of a 32-bits processor with 32KB of RAM and 256KB of FLASH memory. This solution offers enough program storage and memory space to support multiple auxiliary sensors. This chip is used by the Arduino Zero and MKR boards, therefore benefiting from the open community built around these boards in particular and the Arduino project in general. Second, the platform is a front and backend solution for ingesting, storing and interacting with public data with a particular focus on crowd sensing applications, as illustrated in Figures 4.20 and 4.21.

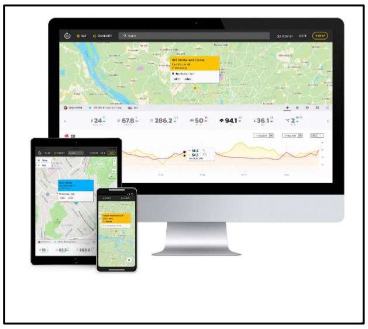


Figure 4.20. SCK platform

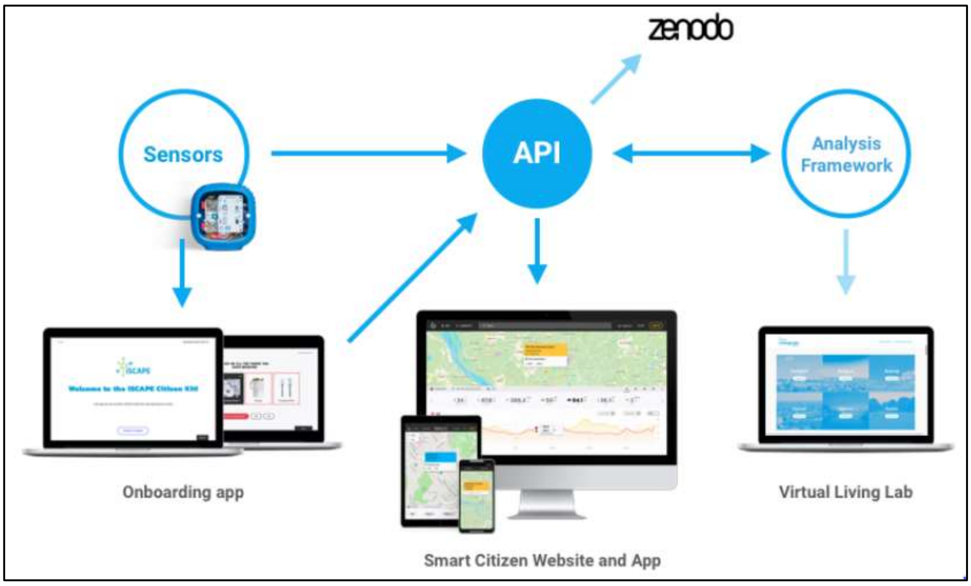


Figure 4.21. SCK modular and reusable software.

As illustrated in Figure 4.21, the software components are:

- Smart Citizen Website: It aims to provide a visual website where the project environmental sensors can be accessed in near real time to facilitate the exploration of data with other contextual data (maps, keywords) and processed reports. This is especially important towards citizens engaging at each local site having a sense of ownership over a technology intervention has been associated with sustained community engagement (Balestrini et al. 2014). The main instance its available at smartcitizen.me/kits, where it is possible to explore and contribute to the source. It is a free software available under GNU Affero General Public License (AGPL).
- Smart Citizen API: The platform provides a REST interface for all the functionalities available on the Website. That allows applications to be developed on easily on top having access to all the features to create complex and rich tools. The main instance its available at api.smartcitizen.me. You can explore and contribute to the source. One examples of this tools is the Sensors Analysis Framework or the iSCAPE Virtual Living Lab, both developed during

the iSCAPE project) This is free software available under GNU Affero General Public License (AGPL).

- Onboarding app: It aims to facilitate the process of sensor setup to ensure that users, irrespective of technical expertise, can install the sensors. It guides the user through the process of the setup using simple language and a friendly graphic language. It is built as a separate tool from the core Smart Citizen Webpage in order it can be customized for each deployment. It exchanges data with the core platform using the Smart Citizen API.

The sensor analysis framework illustrated in Figure 4.22 has been written in Python, a programming language that permits to work quickly and integrate systems more effectively. It is intended to provide a state-of-the art data analysis environment, adapted for the uses within the Smart Citizen Project, but that can be easily expanded for other use cases.

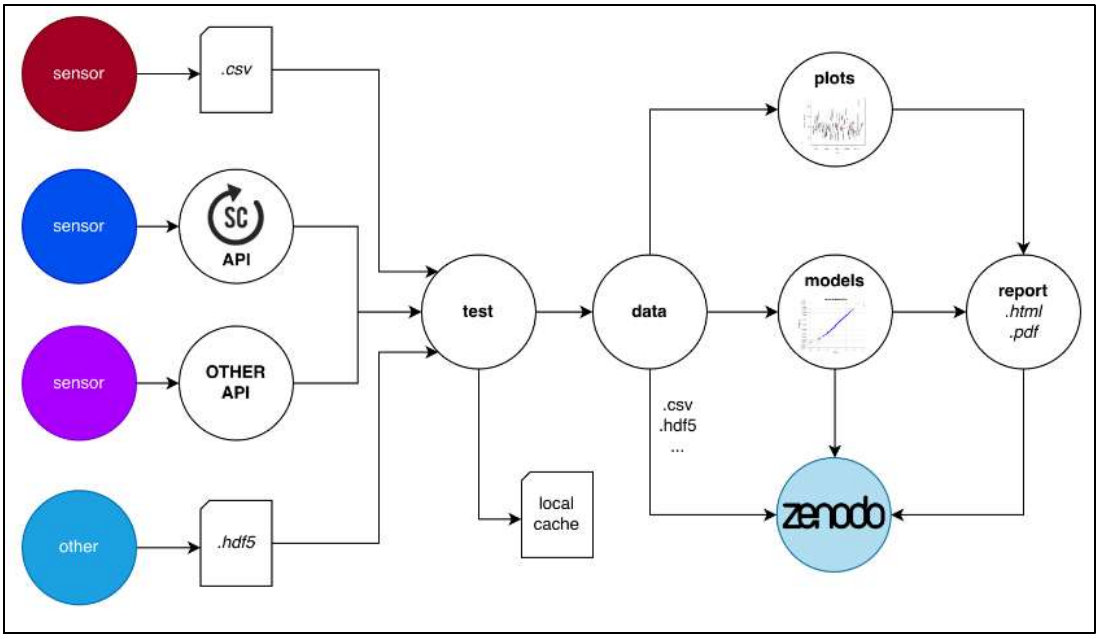


Figure 4.22. SCK sensor analysis framework.

Figure 4.22 shows how the raw sensor data from the devices is sent to the Platform and processed outside of the sensors. Raw data is never deleted, and the postprocessing of it can be traced back to its origin by using the sensor blueprint information. This way, we guarantee openness and accessibility of the data for research purposes. The framework is integrated with the Smart Citizen API and helps the analysis of large amounts of data in an efficient way. It also presents a functionality to generate reports in html or pdf format, and to publish datasets and documents to Zenodo, an open repository developed under the European OpenAIRE program and operated by CERN. It allows generally researchers to deposit research papers, data sets, research software, reports, and any other research related digital artefacts. The framework allows downloading data from the Smart Citizen API or other sources, as well as to load local csv files. Then, different data explorations options are readily available, and not limited to them due to the great visualisation tools in python. Finally, permits to generate html or pdf reports for sharing the results. It contains also a sets of statistics and machine learning able to permit sensor data calibration.

The SCK kit described above is part of the Sensor pack designed in cooperation with FabLab Barcelona. The sensor pack is comprised of these components:

- Smart Citizen Kit 1 with GPS and antenna.
- USB charger and cable.
- Customized enclosure.

The sensors components are illustrated un Figure 4.23.

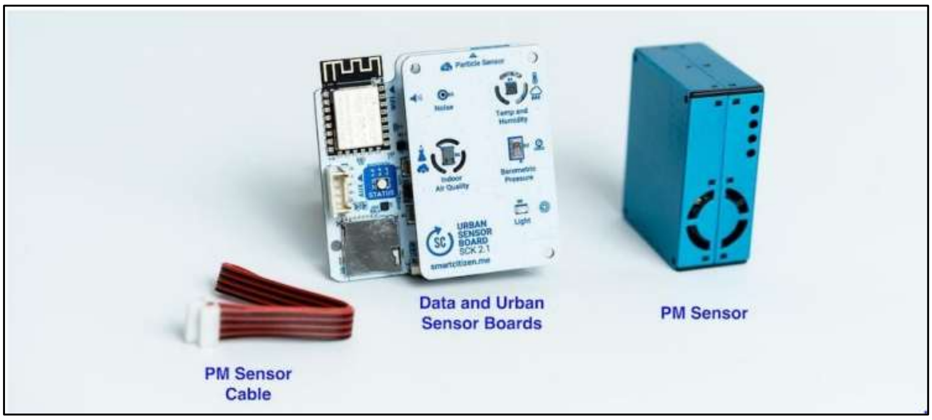


Figure 4.23. Sensors components.

In particular in Table 4.3 is showed the type of sensors used specifically.

Measurement	Units	Sensor
Air temperature	ºC	Sensirion SHT-31
Relative Humidity	%RH	Sensirion SHT-31
Noise level	dBA	Invensense ICS-434342
Ambient light	lx	Rohm BH1721FVC
Barometric pressure	kPa	NXP MPL3115A26
Equivalent Carbon Dioxide	ppm	AMS CCS811
Volatile Organic Compounds	ppb	AMS CCS811
Particulate Matter PM 1 / 2.5 / 10	μg/m3	Plantower PMS 5003

Table 4.3. Sensor types and measurement.

The GPS has been accurately chosen to grant specific standard. The selected NEO-M8U GPS Breakout from Sparkfun 2 is a high-quality GPS board. The NEO-M8U takes advantage of u-blox Untethered Dead Reckoning (UDR) technology. The NEO-M8U module is a 72-channel u-blox M8 engine GNSS receiver, meaning it can receive signals from the GPS, GLONASS, Galileo, and BeiDou constellations with ~2.5 meter accuracy. The module supports concurrent reception of three GNSS systems. The combination of GNSS and integrated 3D sensor measurements on the NEO-M8U provide accurate, real-time positioning rates of up to 30Hz. Compared to other GPS modules, this breakout maximizes position accuracy in dense cities or covered areas. Even under poor signal conditions, continuous positioning is provided in urban environments and is also available during complete signal loss (e.g. short tunnels and parking). Lock time is further reduced with on-board rechargeable battery; there is a backup power enabling the GPS to get a hot lock within seconds.

More in details, the NEO-M8U module introduces u-blox's Untethered Dead Reckoning (UDR) technology, which provides continuous navigation without requiring speed information from the vehicle. This innovative technology brings the benefits of dead reckoning to installations previously restricted to using GNSS alone, and significantly reduces the cost of installation for after-market dead reckoning applications. The strength of UDR is particularly apparent under poor signal conditions, where it brings continuous positioning in urban environments, even to devices with antennas installed within the vehicle. Useful positioning performance is also available during complete signal loss, for example in parking garages and short tunnels. With UDR, positioning starts as soon as power is applied to the module, before the first GNSS fix is available. The NEO-M8U may be installed in any position within the vehicle without configuration. In addition to its freedom from any electrical connection to the vehicle, the on-board accelerometer and gyroscope sensors result in a fully self-contained solution, perfect for rapid product development with reliable and consistent performance. The intelligent combination of GNSS and sensor measurements enables accurate, real-time positioning at rates up to 30 Hz, as is needed for smooth and responsive interactive applications. Native high rate sensor data is made available to host applications such as driving behaviour analysis or accident reconstruction. The NEO-M8U includes u-blox's latest generation GNSS receiver, which adds Galileo to the multiconstellation reception that already includes GPS, GLONASS, BeiDou and QZSS. The module provides high sensitivity and fast GNSS signal acquisition and tracking. UART, USB, DDC (I2C compliant) and SPI interface options provide flexible connectivity and enable simple integration with most u-blox cellular modules. U-blox M8 modules use GNSS chips qualified according to AEC-Q100 and are manufactured in ISO/TS 16949 certified sites. Qualification tests are performed as stipulated in the ISO16750 standard: "Road vehicles – Environmental conditions and testing for electrical and electronic equipment". In Figure 4.24 has been showed the main NEO-M8U product features.

Model	Category				GNSS					Supply	Interfaces				Features								Grade		
	Standard Precision GNSS	High Precision GNSS	Dead Reckoning	Timing	GPS/QZSS	GLONASS	Galileo	BeiDou	Number of concurrent GNSS	2.7 V – 3.6 V	UART	USB	SPI	DDC (I²C compliant)	Programmable (flash)	Data logging	Additional SAW	Additional LNA	RTC crystal	Oscillator	Built-in sensor	Timepulse	Standard	Professional	Automotive
NEO-M8U			UDR		•	•	•	•	3	•	•	•	•	•	•	•			•	C	•	1		•	

UDR = Untethered Dead Reckoning / C = Crystal

Figure 4.24. GPS NEO-M8U features.

The SparkFun NEO-M8U GPS Breakout is also equipped with an on-board rechargeable battery that provides power to the RTC on the NEO-M8U. This reduces the time-to-first fix from a cold start (~26s) to a hot start (~1.5s). The battery will maintain RTC and GNSS orbit data without being connected to power for plenty of time, as showed in Figure 4.25.

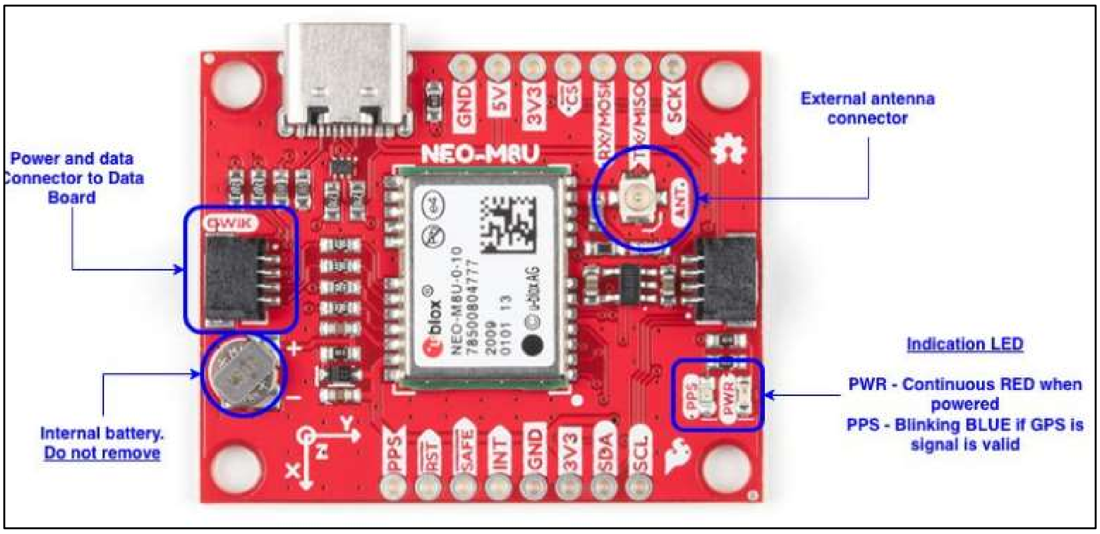


Figure 4.25. SparkFun NEO-M8U GPS Breakout.

The GPS uses a Molex ceramic patch antenna 3 4 with 4.5dBi gain and 1.561GHz, 1.575GHz, 1.602GHz frequencies.

4.3.3. Settle bag study

The enclosure was specifically chosen for the following reasons:

- It is a widely available enclosure by a well-established bike equipment manufacturer;
- Size and materials: lightweight and waterproof;
- Flexible outer fitting for low vibrations and transmissibility. The sensors are internally suspended by a polypropylene folding and the air intakes are made out of 3D printed PLA.

In Figure 4.26 is illustrated concept, while in Figures 4.27 and 4.28, it is showed the early applications of the settlebag on a bike at DICAM, on the basis of the development conducted in cooperation with Fablab Barcelona.

Figure 4.26. Settlebag concept.

Figure 4.27. Settlebag testing allocation at DICAM.

Figure 4.28. Settlebag testing allocation detail.

The sensors are enclosed in the saddle bag in order to avoid dirt and water spills. The measurement method in the enclosure ensures a sufficient air flow parallel to the sensor's surface, and a limited gas speed across the sensors and minimum gas residence time to ensure sensitivity.

4.3.4. Test and validation

The tests performed in cooperation with FabLab Barcelona are:

- Indoor particulate tests.

- Outdoor dynamic vs. static comparison.

- Outdoor dynamic comparison Indoor particulate tests.

These tests were conducted indoor using a Marlin Smoke Machine in order to assess the difference between each enclosure.

A. Free air comparison

An initial comparison between both sensors in open air is done in order to assess the difference between each sensor measuring in open air with smoke injection up to 4000ug/m3. In the figures 4.29, two distinct phases have been highlighted (when there is smoke being injected in the room), and dispersion, when the injected smoke is being dispersed with a fan. Both sensors correlate well in the injection phase and dispersion phases, but they do have an offset in the dispersion phase that is not identified, and that could be simply due to the sensor's position, although they are less than 10cm apart. This maximum offset is 700-1000ug/m3 in an environment of very large particle concentration numbers 3000ug/m3. Temperature and humidity offsets in this case are found to be less than 0.5degC in temperature and negligible for relative humidity.

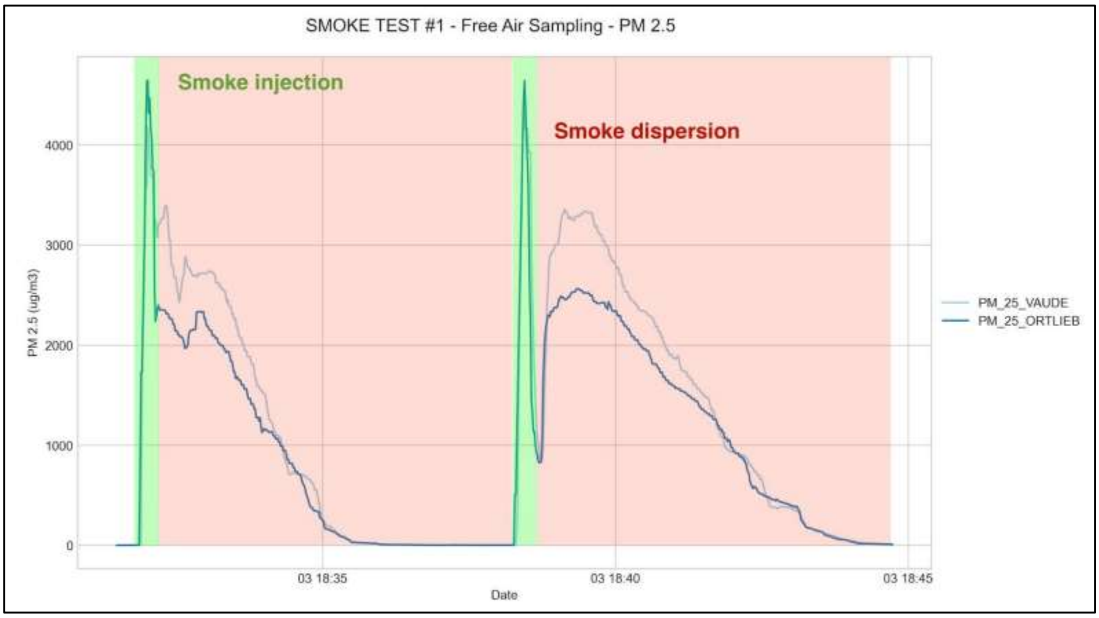


Figure 4.29. Test #1 Free air sampling PM 2.5.

B. Enclosure comparisons

The purpose of this comparison, showed in Figure 4.30, is to determine which measurement principle of the following is the best between:

- directly exposing the sensors to the air flow by the bicycle's movement

- expose them inside a "chamber" in which air flow is contained and briefly slowed down.

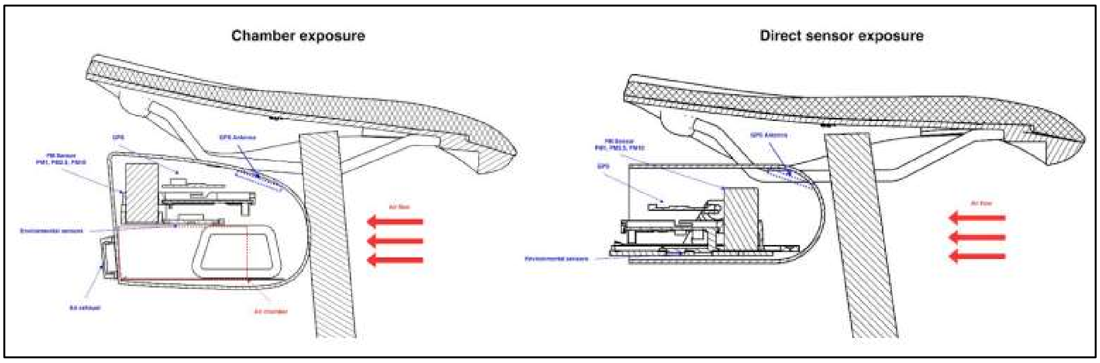


Figure 4.30. Chamber and direct sensor exposure.

The Figure 4.31 shows the comparison of both enclosures mounted on the bike, and a rider on the bike.

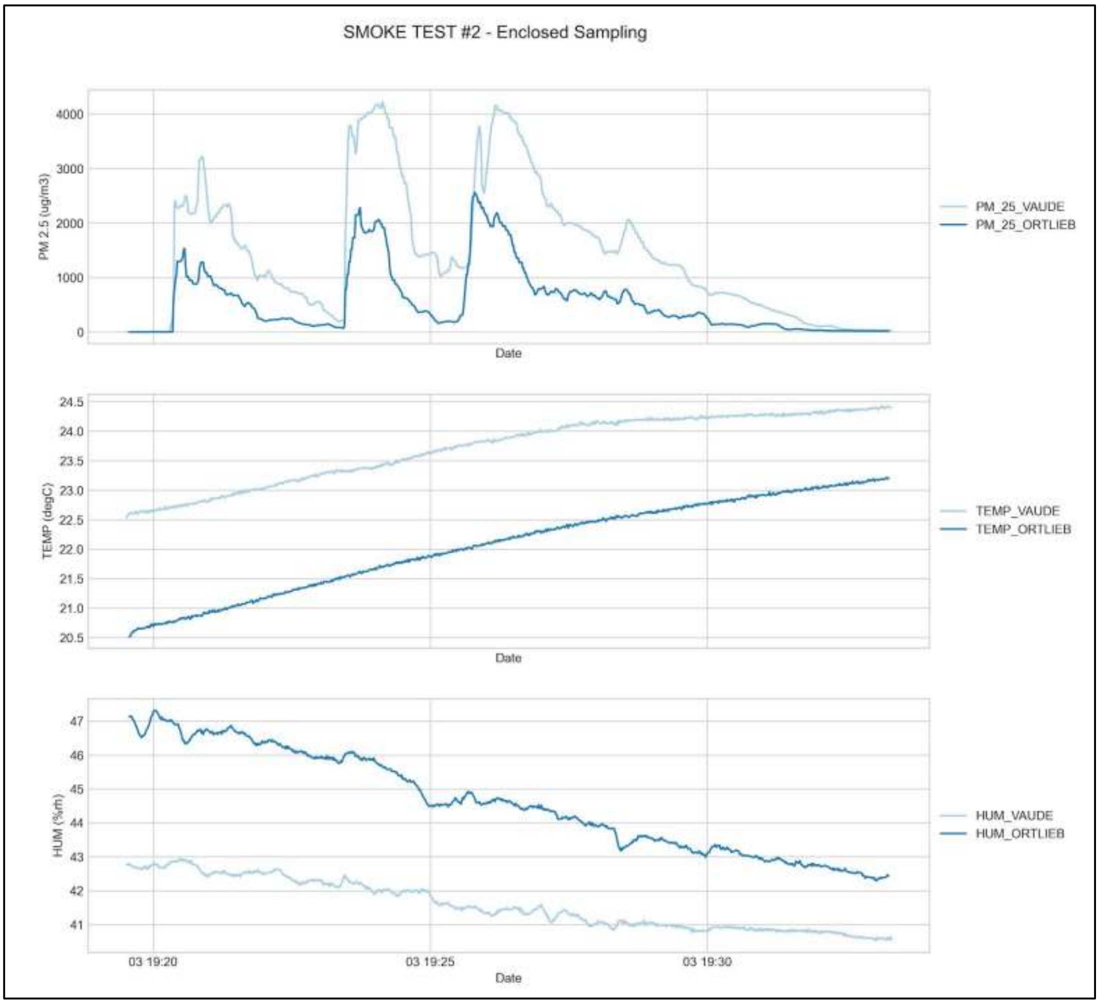


Figure 4.31. Smoke test#2.

The comparison shows that the direct sensor exposure (ORTLIEB in the graph) is not as sensitive to particulate in the air as the chamber exposure is (VAUDE in the graph). This offset is not justified by the offset seen in the dispersion phase in the free air test as it is also reduced in the injection phase. On the other hand, the chamber exposure shows a longer tail in the dispersion phase, as the particles can remain in the chamber and not be fully evacuated, although reactivity to larger quantities remains as seen in the graph below. It also shows that the VAUDE enclosure evacuates better heat generated by the electronics, as the temperature offset between both enclosures is reduced. As seen in the following tests, the offset of each enclosure with respect to real temperature is between 1 to 3 °C and it could be compensated by software a posteriori, but it can't be avoided as the sensors are confined in the enclosure. This factor is not critical for the exposure assessment and decision, as the material of the enclosure differs, and it's less transpiring in the ORTLIEB option.

C. Chamber vs. Reference test

The comparison of the best-so-far enclosure is shown below, with respect to the reference sensor in free air. This comparison shows how the enclosure effectively slows down the air flow charged with particles, and still correlates properly with the free air sensor in the injection phase, although not in the dispersion phase. This indicates that the accumulation and evacuation process of the particles within the chamber is not fully controlled in this enclosure. Nevertheless, the levels of particles in this setup are not comparable to any actual particulate levels found in actual urban environments, as indicated in Figure 4.32.

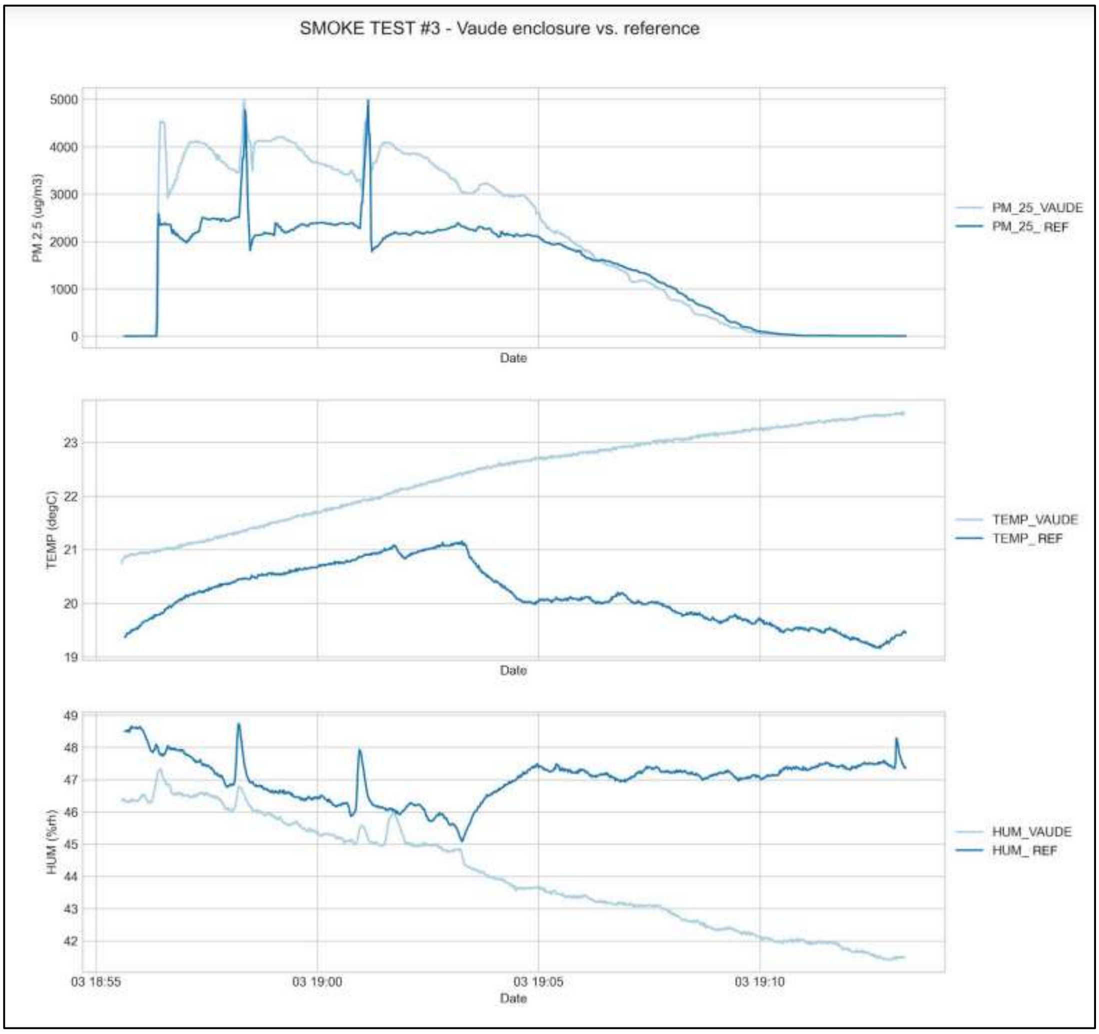


Figure 4.32. Smoke test#3.

The offset in temperature and humidity is of approximately 3ºC at the end of the test, and follows a normal heat up curve with logarithmic trend, equally for humidity with 7%rh.

D. Direct exposure vs. Reference test

The direct exposure vs. reference comparison shows an inferior sensitivity, already seen in the enclosure comparison, of the direct exposure option versus the actual concentration. The measurements also show less reactivity in some instances, smoothing out some peaks in particle concentrations. Temperature trace shows an offset of 3degC at the end of the test, similarly to that of the other enclosure, with a humidity difference of 4-5%rh, as illustrated in Figure 4.33.

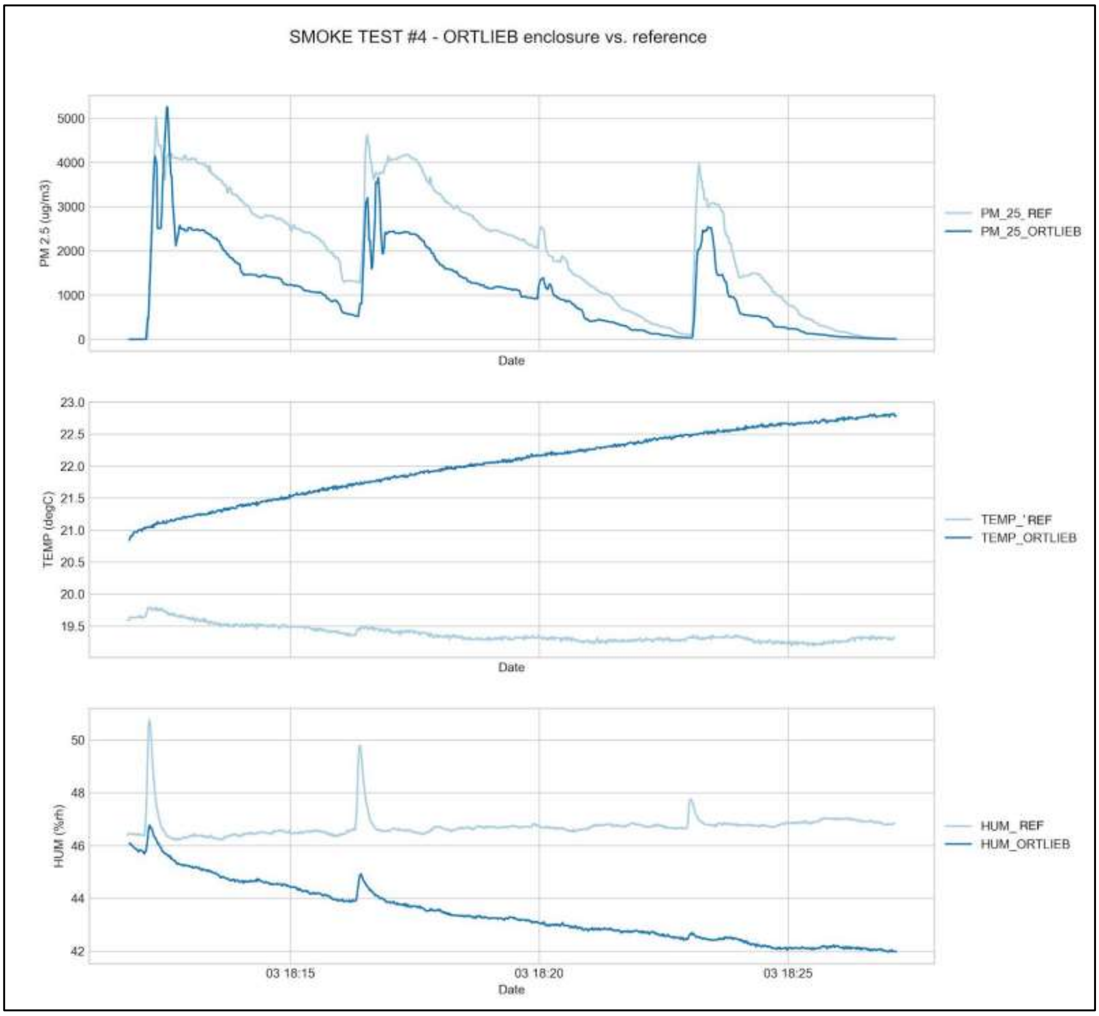


Figure 4.33. Smoke test#4.

E. Outdoor tests

These tests are aimed at comparing outdoor measurements with sensor trips. These measurements use the same sensor as the ones mounted on the bicycle. A script is used to post-process the data based on location and derive a comparison between both measurements.

Comparison bike front vs. bike back

This comparison shows the difference between the different metrics when measuring gas using the same enclosure in the front (black) and in the back (green), as illustrated in Figure 4.34.

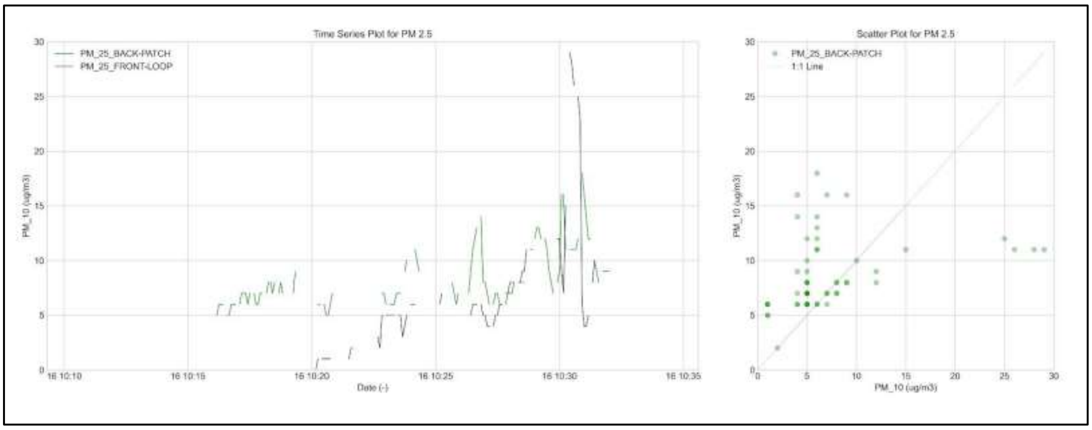


Figure 4.34. Time plot and plot for PM 2.5.

After a short stabilisation period, this test shows that PM2.5 measurements are equally correlated between both positions. In the case of the temperature sensor, a difference of up to 2ºC was seen (higher in the saddle's position), with better sensitivity in the case of the front-sensor, due to a lower confinement and larger surface area.

Due to project guidelines, the saddle position of the sensor is considered sufficient for the purpose of monitoring air quality. However, it's worth mentioning that this sensor location requires attention for the sensors to never be covered by the rider's clothing. Furthermore, the front position shows a better response for the sensor temperature representativity and sensitivity as seen above, with a potential better GPS fix quality. This latter issue is compensated with the usage of an active patch antenna with higher gain.

After test analysis the production of 50 sensors kit has been activated and in July 2021 the provision has been accomplished.

4.4 Privacy policy

In order to start up the experimentation phase with Almabike and sensors it has been submitted the overall issue for evaluation by the Data Protection Manager (DPM) of University of Bologna, in charge of evaluate privacy for each impacting project on university community in terms of personal privacy possible violation.

DPO defined the Impact evaluation document (DPIA), in which identifies privacy impact of Almabike projects on students and staff. In particular, there are some specific issue to take in exam about data treatments.

In particular It has been identified that the release of bicycles equipped with GPS devices installed in the frame is envisaged for the pursuit of the following purposes:

A. Provision of the mobility service through the provision of loan contracts for the free use of 600 bicycles, aimed to encourage environmental sustainability for University students and staff.

B. A scientific research purpose to study the relationship between the city, sustainable mobility and environmental impact, conducted within the Department of Civil, Chemical, Environmental and Materials Engineering (DICAM).

In regards to purpose A) concerning the provision of the sustainable mobility service, the following data has been identified of being processed: association between vehicle and user; name, surname, registration number and e-mail address of the person with whom the loan agreement is stipulated; data relating to the geographical position of the vehicle; kilometres travelled (daily and total).

These data may be processed in the context of the following activities:

a. for the stipulation of the loan contract for free use;

b. in order to protect the university assets, ensuring, for example, that the illegitimate/anomalous movement of the bicycle is signalled through an anti-theft system;

c. for service monitoring purposes;

d. to establish any elements of "c.d. of rewards" in the case of considerable use of the vehicle, to be taken into consideration in the context of future calls for tenders relating to this service.

With reference to what is reported in the context of the activities referred to in point b), in fact, in the event that the theft of the vehicle occurs, it has been underlined the opportunity to receive an appropriate notification through e-mail address.

In regards of the scientific research purposes B) mentioned above, the scientific study aims to investigate some aspects inherent in the field of road design and complex mobility systems (for example with particular reference to the study of the supply-demand balance with a view to analysing the impact of road safety aspects and infrastructural design on the choice of route and ecological behaviour).

The aforementioned scientific research purpose is recognized as achieved through the installation of a special sensor capable of detecting additional data with respect to those already used for the previously described purpose. In particular, it concerns the collection of inertial data (speed and acceleration), as well as the tracking and consequent recording of all the movements made by each single cyclist.

It has been noted that the treatment for research purposes not concern all bicycles, but only 50 bicycles reserved for the exclusive use of University staff (therefore additional to the 600 mentioned in the introduction), in which it had to be detected further environmental data, i.e. the presence of PM2,5 and PM10, the temperature and the humidity through interconnection with the data concerning the distances made in terms of space and time.

Further, about specific responsibilities concerning data treatment, it has be necessary to underline that as part of the service management purposes referred to in point A), the University Construction and Sustainability Area (AUTC) had a role in the collection of student data, in the vehicle-student matching and in identifying the supplier which contractor for the technical management of the service (at the time of drafting this DPIA identifiable in the company INBIS). That company supplied 650 satellite devices to be installed on the bicycles used by the students as part of the "Almabike" project. In particular, the data will be processed by tracking the positions of the bicycles, using GPS systems with anti-theft functions.

Personnel authorized to data treatment has been defined in Mobility manager and related staff.

Finally, as part of the pursuit of research purposes, it has been recognized that AUTC and DICAM manage the selection call, in the context of which the authorization of the interested part is also acquired with reference to the processing of data for scientific research purposes. AUTC manages the position data and the air quality data deduced from the sensors installed on board the vehicles. DICAM may have access to the aforementioned data for research purposes, with exclusive treatment by professors, researchers and PhD students.

Following the DPIA, it has been defined two different Privacy policies for each side of the Almabike project, for loan contracts for the free use of 600 bicycles and for Research purposes contract for use of 50 bicycles integrated by sensors pack. In each Privacy policy document has been reported the kind of data treatments as a condition to accept to use bicycles.

Chapter 5. Almabike research methodologies

5.1. Purposes and operational

In compliance with consideration exposed in Chapter 1, Almabike general purposes have been defined as:

- Study the students' cyclists behaviour, with the aim to analyse this specific category;
- Study the environmental impact on routing, evaluating in statistic terms effect on university cyclists of crowdsourcing air quality detection.

Once the 650 Almabikes have been provided and all integrated with GPS trackers, while in parallel 50 sensors packs were in development phase, University of Bologna Students Office and Mobility manager, published a series of calls for all students of first and second degree, without limitations of targeted samples (by gender or type of students, etc), in order to distribute the bicycles and start monitoring the behavioural issues, between November 2020 and march 2021, reaching out more about 600 students.

5.2 Almabike for university students' cyclists

The GPS sensors have been integrated by an online application, for Smartphone and PC access through registration of users, that permits students to have real time vision of owner bike positions and also may activate anti-theft alarm in case of unauthorized movements of bikes. Student participants were free to move in urban territories of Bologna on the basis of their daily personal commuter and travel planning, without boundaries of mandatory passages on specific lanes or pre-defined days of tripping. The bicycles were given to students as a sort of long term personal loan.

The territorial limits emerged spontaneously during the trips and are represented by the Centre of Bologna, mainly, even if some trips consider also more peripherical context. Figure 5.1 shows the Bologna city centre and the main University buildings. The red perimeter represents the city historical limit; where once a wall defended the city, nowadays a well-designed cycle-path ("Tangenziale delle biciclette", Italian for "Cycle Ring-road") allows cyclists a safe ride.

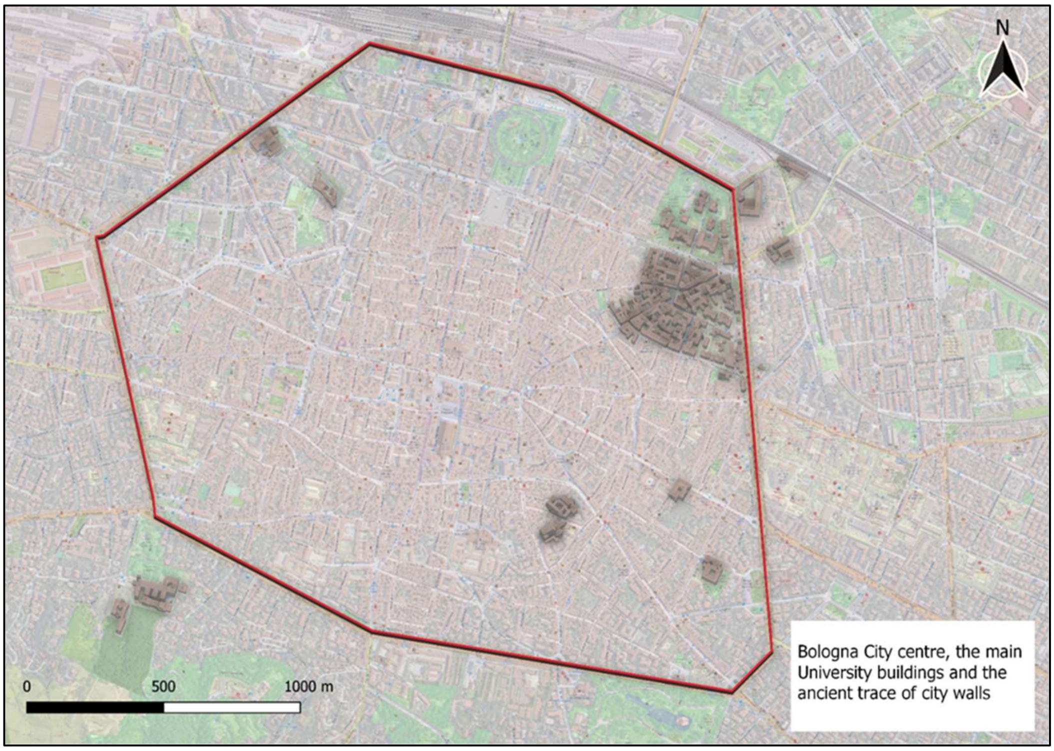


Figure 5.1. Territorial limits.

Raw data were registered by GPS sensors installed on the bicycles. The sensors had to be manually recharged by users. Sensors were able to automatically save one entry per minute averagely, and the recorded information were both spatial (the coordinates) and temporal (day and time). All the information was univocally associated to the pertinent bicycle. With respect to privacy limitations, during the data analysis it was never possible to identify the user identity, and the bicycles were recognizable only by an anonymous ID code. The GPS spatial accuracy for this application was 5 meters. This value, when sensors receive the signal under ideal conditions, can be generally accepted (Schuessler et al., 2009), but at this stage of analysis, the mentioned spatial accuracy and the absence of complementary devices or data sources introduce some problems in the assessment of cycle paths usage and choices, with particular regards for tripping along the roadway (Pritchard et al., 2018). To find specific relevance about cyclists' behavior, it has been developed a short online survey limited to Almabike users with the aim to detect specific information able to integrate the GPS data analysis, as illustrated below.

Before starting the analysis, a deep data review was conducted in order to filter the out layers from the set of data and to increase the overall database value. In fact, according to Naumov (2019) and Schusessler (2009), GPS-based analyses should be conducted within a specific workflow, which should contain different steps, from database overview and cleaning to map matching. In this work it has been used a definite workflow whose main components are already applied and validated by the cited previous works. The preliminary scrutiny, as the rest of the analysis, was conducted by using GIS (QGis software, 3.16 version), spreadsheet (Microsoft Excel) and business intelligence (Microsoft PowerBi) softwares. Some filtering conditions were manually elaborated, while most of the used algorithms are based on the software features (native or specific plug-ins).

A deep general overview of raw data was operated in order to solve most of the recurrent biases and errors registered during the recording such as incoherent tracing and position accuracy of the GPS receiver in function of urban shape and urban canyon impact, that may reduce data quality (Schuessler et al., 2009). In order to focus the analysis on Bologna and the surrounding municipalities where Almabike usage was registered (i.e., Casalecchio di Reno, San Lazzaro di Savena, Sasso Marconi and Zola Predosa), a spatial filter was applied. Albeit Almabike vehicles were distributed to the entire university population, records outside the metropolitan area of Bologna were discarded. This constraint was required due to both statistical (about 59% of original records were registered within Bologna and its surroundings) and technical (reference data and GIS layers were more structured here) reasons. GPS sensor outputs were structured in .csv files; every record was characterized by a set of attributes such as the ID number of cycles, the timestamp (hours, minutes, seconds and the date) of GPS records and the coordinates (in WGS84 reference system). Another attribute related to the speed was not correctly recorded due to GPS biases. However, even if is less accurate than the computed one (Pucher et al., 2009), speed was calculated on the basis of timestamps of succeeding points. After the overview, a database extension was performed. Starting from the original attributes, some other fields were calculated. These elaborated fields were meaningful to increase the value extracted from the original data because they gave the opportunity to detect the starting point of a new trip, to deeply study the time distribution of the Almabike usage, according to the date and the time and to deeply analyze the users' behaviors and usage (how many trips were made within the reference period, which is the average speed and trip length, which are the predominant origin/destination patterns, etc.). These new fields were calculated by taking into account the characteristics of GPS data such as the GPS sensor average recording interval and the so-called "warm start/cold start problem", which means that, during a GPS survey, some points are missing at the beginning of the trip because of the GPS receiver need of acquisition of the position of at least four satellites in view (Schuessler et al., 2009, Pritchard et al., 2018). After overviewed and extended the database, an exhaustive map matching procedure was conducted. As Park stated (Park et al., 2019), during a GPS survey analysis, map matching is a necessary procedure to determine travelled distance and to count the number of trips along a specific street or path. Consequently, original coordinates were translated and snapped to the road network through QGis. Figure 5.2 shows the differences between non-processed, original GPS records (red points) and processed records (blue points).

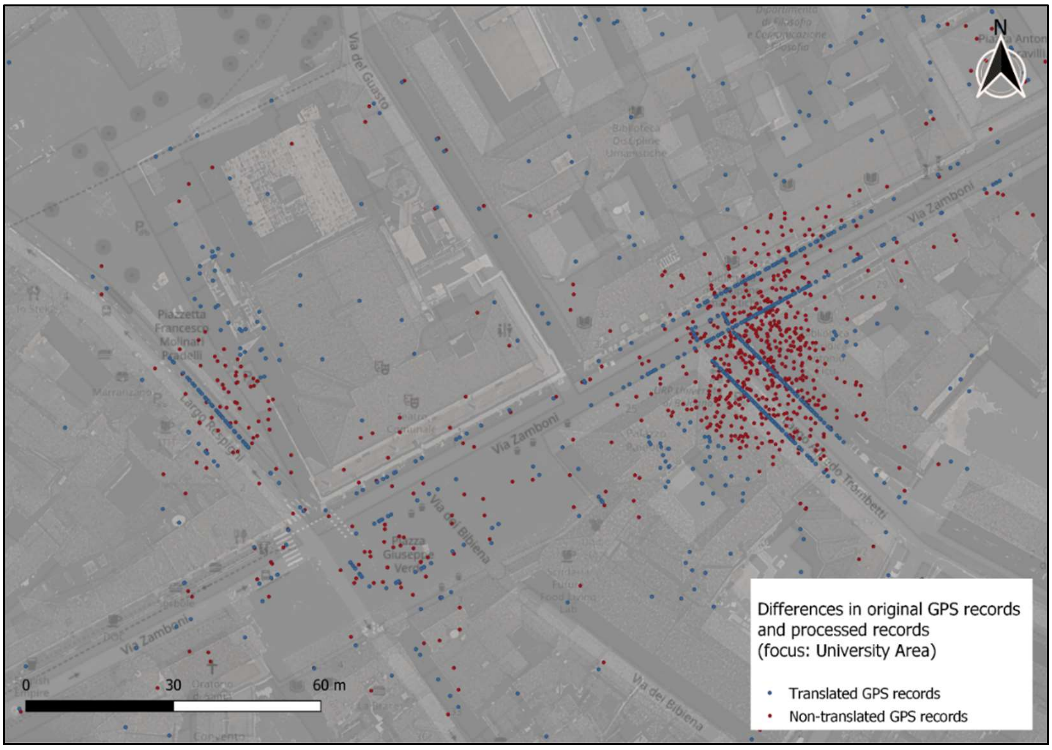


Figure 5.2. Differences in original GPS records and processed records.

Thanks to the unique ID field, every point was always correctly detectable. In addition, a more detailed characterization of points was conducted. Even if cyclists usually prefer non-interrupted routes, they may face elements and variables both in natural and built environments that affect the entire trip which can change trip directions. It means that the global journey speed decreases, and consequently the covered distance is shorter, within the equal time span, than the average. In these cases, even if spatial and temporal attributes are appropriate, records are affected by the presence of some obstacle to the free flow. In order to properly detect all those short movements which cannot be counted as part of a non-interrupted trip (e.g., moving bicycles during the parking manoeuvres, positioning for the green light, waiting for the 'free spot', etc.), it has been used entities like traffic lights, road crossings and bike racks positions and consistency by datasets in Bologna and its surroundings from OpenStreetMap database and uploaded in QGis; these entities were encompassed by a 20-meter-wide buffer. In these terms, records within the given buffers were detected. Figure 5.3 shows an example of this analysis: the location – Porta San Donato – is a crowded node of mobility close to some University of Bologna buildings and facilities such as University museums and administrative offices, and due to the heavy traffic involving the roads, a complex system of traffic lights has been set. In order to provide appropriate parking services, lots of racks were placed here, both within the University area (within the courtyards) and in public spaces.

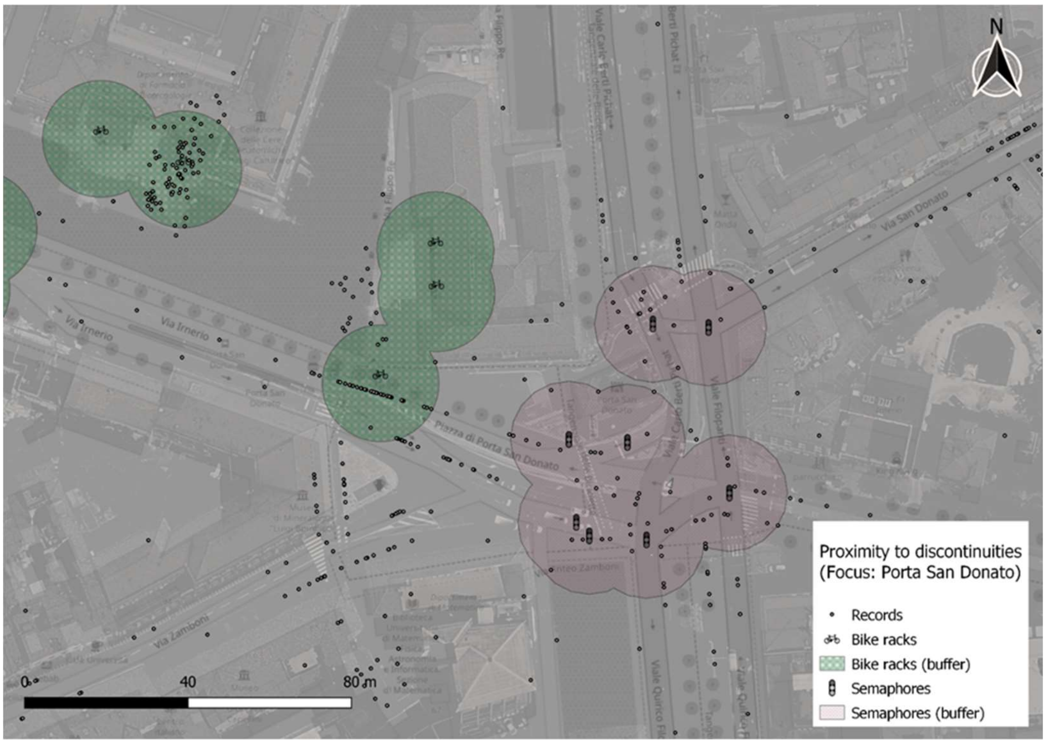


Figure 5.3– Proximity to discontinuities records.

The operations of data review has been in synthesis conducted using the following actions:

- cleaning of positions outside the analysis boundaries;
- reducing the positions in which the bikes were stopped (easily recognized by an anomalous cloud-density of points). Some points reduced were: intersections with traffic lights, bicycles parking lots or at home during;
- Reducing the point in anomalous positions. I.e. in the highway (in which probably the bike has been transported with the GPS aboard a vehicle);

- Map match of incorrect points. Through a 20 metres buffer the points has been automatically reallocated in lanes.

In addition to deepening the analysis, with the aim to integrate observation through GPS tracking with more qualitative information about perception of usage and comfort of Almabike users, it has been defined an online survey based on Google form. It has been submitted by mail to all Almabike users. The questions were structured in four sections, as indicated in Table 5.1. Section A is oriented to investigate which level of confidence and comfort the users had about Bologna road net, specifically in function of the place of origin for daily commuting. The aim was to discover how a student may be nudged to use bicycle, through the use of not property bike in the term of being more confident with the urban territory and structure. Section B was typically addressed to understand if the bike was used for daily commuting home-University and to evaluate if COVID19 has introduced some sort of behavioural change. Section C is structured to find the specific role of Almabike in the users's general attitude towards cycling, in particular if Almabike has induced an effect on users's mobility choice of means and if there were some links between Almabike as a not property bike and ride in safety on a cyclepaths. Section D explored primary the reason for Almabike usage in function of the level of satisfaction. The question about the usage has been placed in second position in respect of question about the level of satisfaction, under the theoretical approach of Tversky and Kahneman (1974). The approach was oriented to reduce cognitive anchorage biases.

Thematic sections	**Questions submitted**
A - Questions about the users' profile and their knowledge about the urban form	During the Almabike use, did you live in Bologna?
	In which neighbourhood/municipality did you live?
	Were you already confident with Bologna city (i.e.: were you able to orient yourself within urban structure?)
	How did you get to the University before Almabike?

B - Questions about mobility behaviours	Has Covid19 impacted on your mobility choices?
C - Questions about vehicle usage	Did Almabike affect your mobility choices?
	When you were riding your Almabike, did you use to ride more frequently on cycle paths
D - Questions about users' satisfaction	I was frequently used to mainly cycle Almabike... - for study reasons - for leisure or week end travel - for personal daily needs (i.e. shopping, nightlife, etc.)
	According to your experience in the usage, how much are you satisfied of Almabike (please indicate a value, where 1=totally unsatisfied, and 5 = totally satisfied)

Table 5.1 – Questions of Online survey for Almabike users.

5.3 Supporting instruments development: a data visualization application

As introduced in Chapter 1, a part for the research has been oriented to crowdsourcing methodologies. In this issue, the main key aspect has been to grant, on a minimum daily basis, cyclists' availability to environmental data detection. This information should be geo positioned, permitting to evaluate pollutants associated with lanes and paths.

To address this level of data accessibility it is relevant to observe how sensors recover and permit to download the data themselves. Indeed, the procedure offered by sensors, illustrated in Chapter 4 – paragraph 4.3.2, is structured on two alternative methods:

1. Through SD card present aboard the motherboard of SCK sensorpack.

2. Through wi-fi connection.

The first scenario is simplest, but depends basically on the level of availability of the participants to download data on their own. That means the risk of an instable and not periodic data harvesting. The second scenario, based upon wi-fi system, offers theoretically an automatic opportunity to download data during the day, but presents also a problem on university wi-fi, characterized by institutional accreditation. Consequently wi-fi had to be implemented only using Wi-Fi disjoined by university wi-fi. On that basis an integrated data harvesting in which participants should choose between two download options has been evaluated.

In late 2021 it has been designed and created a special hot spot wi-fi, placed in Palazzo Poggi, via Zamboni 33, hosting the Rector's main offices and located within the very centre, among several others university buildings.

Far beyond expectation, even if hot spot Wi-Fi functions regularly, the downloaded data did not have geo-spatial reference information, and it has been discovered that only environmental data recurring in last position were downloaded. That critical aspect reduced strongly the real field of application of automatic download, establish as unique solution for download data the SD card method.

By the way, that scenario changed and real time data were not possible to share among participants. The best way to share crowdsourced data was to define a common point of reference. This point should be a virtual one, a sort of space in which any user should see his data and the ones detected by others, with an evident time span between detection and data observation. At least it was a span close to 10 hours between environmental parameter detection and viewing by all users.

Consequently in cooperation with Department of Computer Science and Engineering, has started the development of a web application for data visualization, able to represents on map environmental data collected through sensors.

As detailed in paragraph 5.3, since pollutants data are transmitted by sensors about any 5 seconds, the overall daily volume of data was huge. The web system should have to make several average values, on physical and temporal dimension.

In these terms the first simplification has been to adopt range of pollutants value in order to reduce the dispersion. It has been chosen to adopt normative range, for each pollutant, as illustrated in Table 5.2

Pollutant	**Range**	**Condition**	**Colour**
PM 10	<20milligrams/mc	No effect on health	Green
	Between 20 and 50 milligrams/mc	Alert, possible effect on health	Yellow
	> 50 milligrams/mc	Warning, impact on health (normative limit)	Red
PM 2.5	< 10milligrams/mc	No effect on health	Green
	Between 10 and 25 milligrams/mc	Alert, possible effect on health	Yellow
	> 25 milligrams/mc	Warning, impact on health (normative limit)	Red
Volatile organic compound (VOC)	<0.3 milligrams / m3	Low exposure	Green
	Between 0.5 a 3 milligrams/mc	Acceptable exposure	Yellow
	> 3 milligrams&/mc	Relevant/high exposure	Red
Noise	<50 dB	Low exposure	Yellow
	Between 50 and 60 dB	Alert	Red
	>60dB	Warning: relevant exposure	Green

Table 5.2. Range of pollutants applied in web application.

The application is based on a client-server architecture. In particular, the server is built using the Node.js language and using express.js, a framework that is based on node.js and helps in managing the server itself and routing.

To memorize the data relating to the readings of the sensors, the bikes and the various administrative users, a relational database was created, in particular MySQL was chosen as the open source management system. The choice of a relational database was made on the basis of the data obtained from the various readings, in fact within them there is a structure that can be perfectly represented with the use of a relational model.

As for the front-end, the Angular.js open source framework was used. For displaying the graphs, Chart.js was used, which is an open source Javascript library that allows the creation of graphs, including interactive ones, through the HTML5 canvas element. Furthermore, for displaying the map, the Leaflet library was chosen, which is one of the most well-known open-source JavaScript libraries for creating interactive and mobile-friendly maps. Bootstrap framework was used to ease the process of developing responsive and mobile-first web applications. Figure 5.4 illustrates the web application design in terms of communication between different components within (User-Angular-Typescript-Golang-MYSQL).

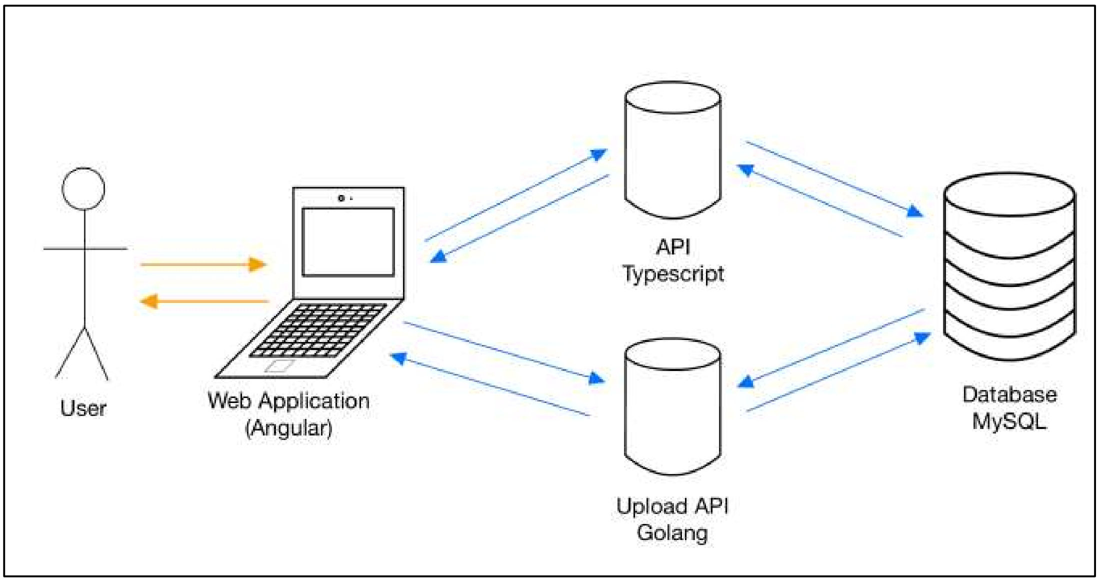


Figure 5.4. Communication between components involved in web app design.

The database was created with the help of Docker. This allowed for an easy installation of all MySQL system. Inside the docker-compose it has been specified the image to use, the platform, the port, the volume where the db is stored (if it does not exist it is created a new volume and initialized a new db), some environment variables and the network to use for communication with other containers, as indicated in Figure 5.5.

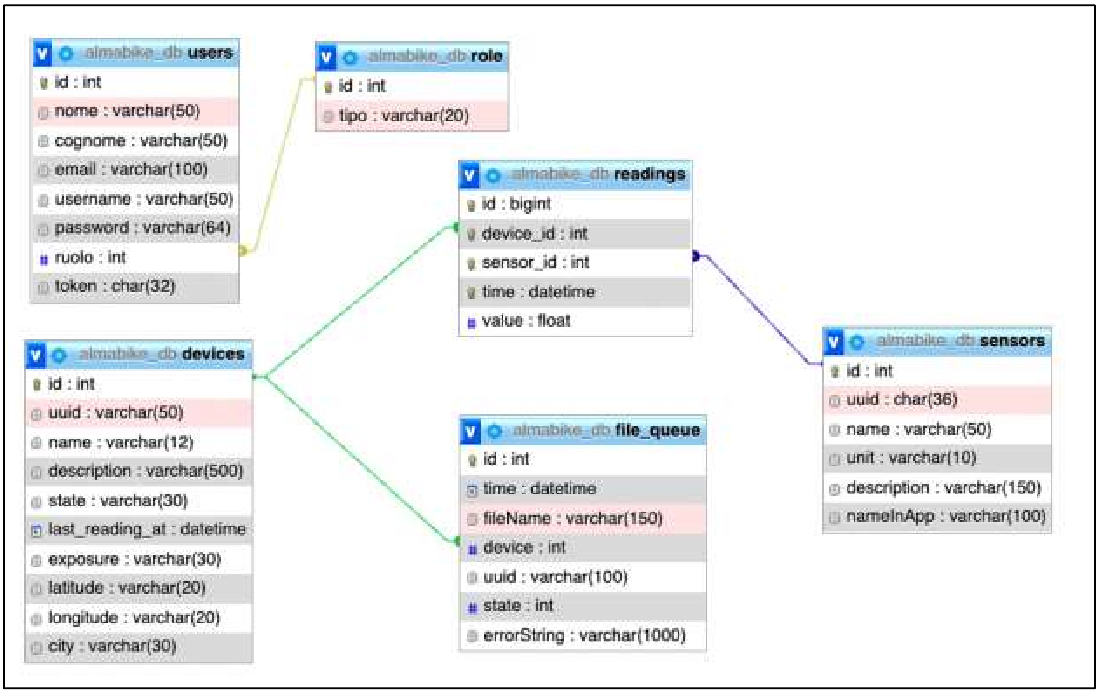


Figure 5.5. Web app logic scheme.

The web application has been finally structured on two different pages. One permits the complete visualization of the heat island of pollutants detected, the other offers a data upload form to feed the map.

User may choose the period of observation, form one day till set of months, and may select the time span in terms of hours. Basically the choice offer a initial and end moment of observation, through access to calendar.

The web application is still available at the address:
http://isi-studio8bis.csr.unibo.it:25122.

In Figures 5.6 – 5.13 are illustrated the visual map of each pollutant heat island. The map includes the opportunity to pass from a general urban overview, as represented in Figures 5.6, 5.8, 5.10 and 5.12, to zoomed ones in which it is possible to view details on lanes or arcs (meaning portion of lanes, separated by crossroads/nodes).

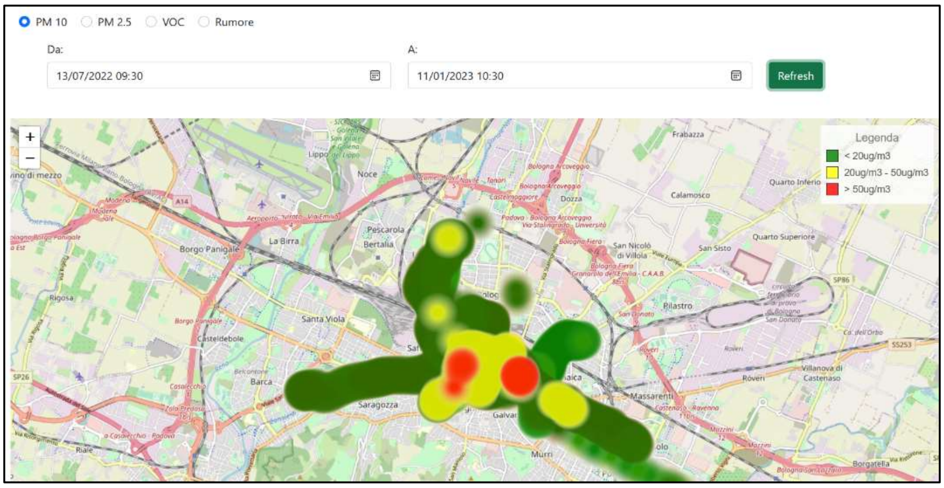


Figure 5.6. Visual map PM 10 – general overview.

Figure 5.7. Visual map PM 10 – lanes detailed view.

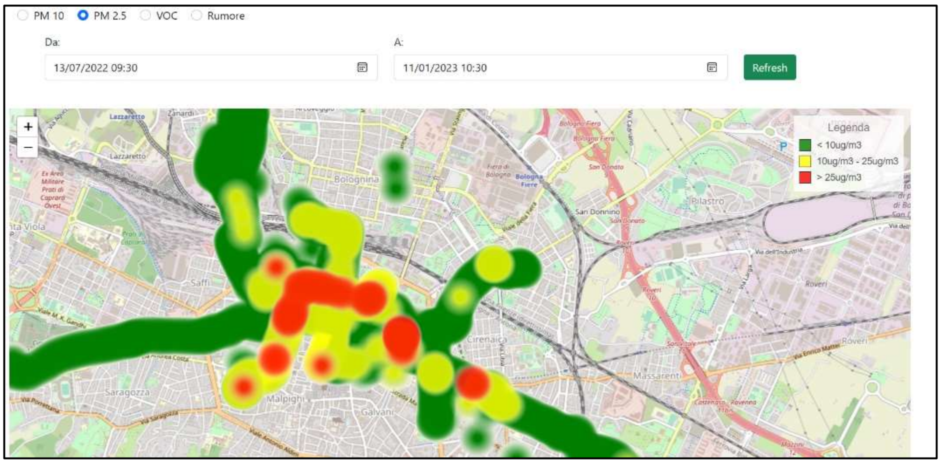


Figure 5.8. Visual map PM 2.5 – general overview.

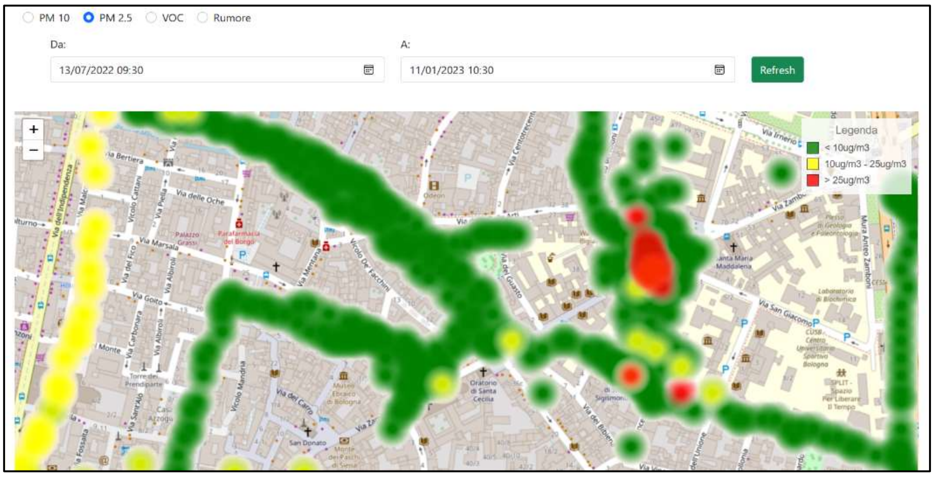


Figure 5.9. Visual map PM 2.5 – lanes detailed view.

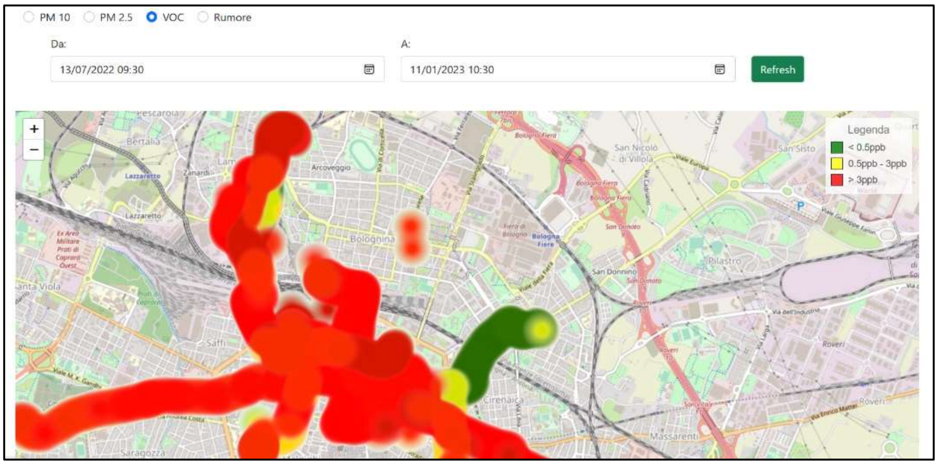


Figure 5.10. Visual map VOC – general overview.

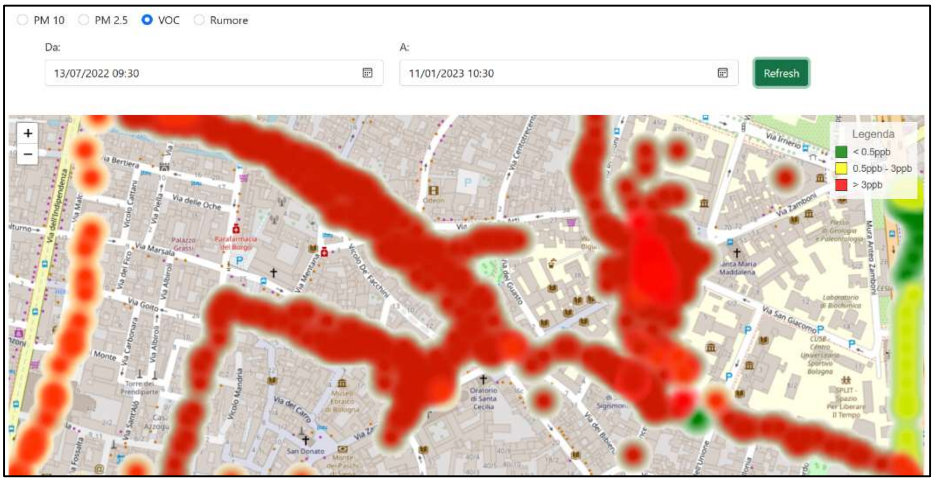


Figure 5.11. Visual map VOC – lanes detailed view.

Figure 5.12. Visual map Noise – general overview.

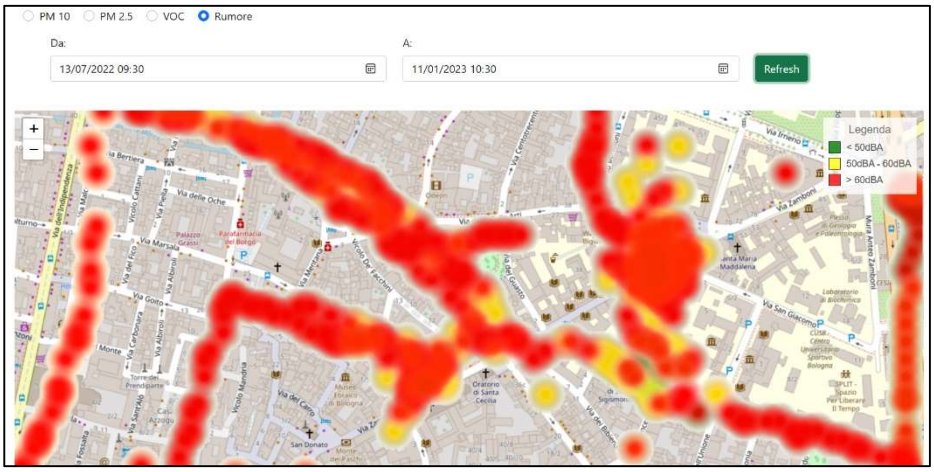


Figure 5.13. Visual map Noise – lanes detailed view.

The methodology adopted to evaluate impact of environmental information awareness on cycling is illustrated in paragraph 5.4, and it is based upon the main concept that user have to observe the aforementioned maps, before each journey with bicycles.

5.4 Almabike crowdsourcing research experience

This part of the research takes steps from the selection of participants. Sensors require a particular care, in terms of different aspects: monitoring with daily attention the level of charge, monitoring the lights emitting by the motherboard (signals of mode, i.e. recording data, in pause, breakdowns, etc), general cares. Considering that, as reported in Chapter 2, after pandemic impacts, academic and administrative staff have manifested an increasing interest and attitude towards cycling, while students in general in a more consolidated bicycles share, expressed a decrease, the selection of participants has been centred on academic and administrative staff only. Moreover the cost of sensors has influenced that choice. Consequently the 50 sensors pack has been distributed to academic and administrative staff. The selection has been made through a specific call, open to all university employees and academics. The selection criteria have been mainly established on the frequency of using the bike on a week basis.

The selection has been published in march 2022, after last tests on sensors as explained in previous paragraph, for 3 weeks duration, and it gains totally about 150 demands. The procedure further proceeded with the phase of explain the project aim and behaviour attended to applicants and then the definitive proposal.

The next phase has been the distribution of bicycles Almabike and sensors kits. This step requires some operative activities: check for the bikes in better maintenance conditions, wheels swelling and main rotative components lubrification, signature of grant agreement and privacy policy, detailed sensors kits function explanation. This step takes about one month among April and May 2022.

Finally, considering some transmitting technical problem found in few sensors and withdrawal of many, driven the number of overall participants to 35.

The aim of the project, as explained in previous chapter, is to start an innovative approach in which investigates the relevance of social ecological conscience in mobility choice, introduced by the concept of awareness of environmental data and impact of these kind of information on routing.

The procedure explained to participants has based upon this travel habit:

a. Before start any journey on bicycle the users must make a check on the web application of data visualization, viewing each pollutants distribution per lanes and path.

b. Act on tripping without limitations, following only their personal agenda and attitudes.
c. Each journey make during the day must be preceded by web app map consulting.
d. Each night the sensor has to be placed on charge and possible turn it on OFF.

On that basis the experimentation/observation phase started in late May till July 2023. The data has been analysed starting from September 2022.
It is however relevant to underline that participants were requested to mount the sensor under the saddle whenever they rode the bicycle. Once they ended their ride, they had to recharge the sensor and to upload the output data (i.e., .csv files) in a web application, explained in paragraph 5.2. Every row of the .csv sheets was a record. Information were spatial (i.e., GPS coordinates, formatted in WGS84 reference system), temporal (i.e., day; dd/mm/yyyy format, and time; hh:mm:ss format) and including environmental variables: humidity, light, noise, pressure, VOC, PM1, PM2.5, PM10.
In order to make the raw dataset as robust as possible, some geoprocessing operations were done. Each processing steps is described as follows: section 5.4.1 describes data revision (i.e., outlier detection, duplicated rows, etc.); in Section 5.4.2 is traced the connotation of road network with environmental data.

5.4.1 Database revision

GPS data need a comprehensive and exhaustive review. In fact, coordinates are exposed to different errors and bias, which should be adjusted before data processing. In dense urban environments, signals could be affected by the presence of buildings, which may cause signal losses and reduction of accuracy and precision. The main aim of database revision procedures was the correction of data by analysing temporal (i.e., time interval between following records) and spatial information (i.e., coordinate errors, irregular sensor recordings) and it was performed in Microsoft Excel, Microsoft PowerBI and QGis (3.16 version).

With regards to the temporal analysis, the whole survey took late April to July 2023. Due to the end of regular academic activities in the late spring and the peculiar sample of users (i.e., university personnel), only a subset of days (i.e., from 16th May, 2022 to 30th June, 2022) was monitored. Sensors recorded data with an average time interval of average 5 seconds. In route analysis based on GPS surveys a 60-seconds temporal resolution could be considered as a pertinent value, so all the data with a time interval between following records ≥5s and ≤60s were saved. As additional temporal characterization of records, a filtering procedure was conducted in order to select only peak hour records (i.e., from 07:30 AM to 10:30 AM and from 04:30 PM to 08:30 PM) and thus observe the exposure during the main commuting time windows.

Spatial analysis was performed mostly in QGis. The coordinate upload in GIS environment allowed the recognition of outliers and unacceptable records. Native geoprocessing tools were applied in order to detect records with wrong coordinates (e.g., Lat = 0; Long = 0) and records outside the study area (i.e., outside Bologna municipality boundaries), while a density analysis was computed to detect inexplicable hotspots. With regards to the latter, some part of the city appeared unreasonably overcrowded during daytime or night-time. The combined analysis of space (i.e., records' coordinates) and time (i.e., day and hour) highlighted a sporadic wrong usage of sensors (e.g., omitted switching off of the sensor after the ride), which caused, for example, a high density of records within university areas during the working hours or nocturnal stationary point clouds next to urban blocks. In addition, and as performed in first part of the research (paragraph 5.2), all short movements which cannot be counted as part of trip (e.g., moving bicycles during the parking manoeuvres, positioning for the green light, waiting for the 'free spot' at road crossings, etc.) were detected by a buffer analysis. To do so, a subset of OpenStreetMap entities (traffic lights, road crossings, cycle racks) were downloaded and processed by a 20-m-wide buffer, and the encompassed records were properly characterized.

Despite the reduction of record amount shown by 5.3, the described operations created a consistent and dense dataset where most of the original users have been monitored. In fact, considering a typical speed of XYZ kmph in urban areas, record density was 11 point per hectare on average. As main apparent result of the map-matching procedure, records distribution is not homogeneous, and most of the records are localized within city centre and at proximities to the university areas (classrooms and offices). This, even if could be seen a quite obvious outcome as bicycles and sensors were assigned to only university staff, was a pivotal factor for the topic of the study, because it allowed a selection of a focus area where record density is sufficiently high and therefore the statistical analyses would be as significant as possible.

Road network length*	m	853,609
Road network length within the city centre*	m	157,997
Reserved cycleway network length within Bologna Municipality*	m	225,151
Reserved cycleway network length within the city centre*	m	39,491

Table 5.3. Road network parameters (*: This value was obtained from the ESRI Shapefile).

5.4.2. Environmental characterization of road network

Once temporal and spatial analyses were completed, records were map-matched by snapping algorithms to the closest road (distance threshold: 20 meters). Map-matching procedure was performed in GIS environment to investigate mobility patterns (i.e., trips) of cyclists and their exposure to pollutants, as detected on singular basis. The official road network shapefile of Bologna municipality was used as reference. Table 5.3 shows the main road network parameters. Data on reserved cycleway network were extracted in GIS by filtering specific attributes of road network, which describes road typologies, and selecting roads where cycle circulation is allowed. In addition, information on green infrastructure, such as canopy coverage, were added to every road segment. Both road network and green infrastructure data were extracted from Open Data web portal of Bologna municipality. By map-matching, both coordinates and information on the recorded environmental parameters were spatially joined to the road arches by pertinent geoprocessing algorithms. Table 5.4 reports the average value and the standard deviation for every analysed environmental parameter; the sample corresponds to the processed database (n = 26,872).

Environmental parameter of records (n = 26,872)	Unit	Mean	St. dev.
Humidity	%	48.47	10.06
Light	Lux	29.52	700.21
Noise	dBA	68.57	13.01
Pressure	kPa	101.01	0.38
VOC	ppb	46.78	95.75
PM1	μg/m3	8.66	7.70
PM2.5	μg/m3	12.33	11.28
PM10	μg/m3	13.11	11.89

Table 5.4. Environmental parameters; average value and standard deviation.

5.4.3 Trips processing

Trips were created in QGis by the application of pertinent algorithms to the processed database. Thanks to the records' attributes, the trips' 'identity' (i.e., the sensor, the day, the time) was always detectable. User identity wasn't recognizable in any case due to privacy limitations, and an anonymous ID code was hence associated to sensors. The procedure created a set of 213 trips, whose main parameters and characteristics are synthetized in Table 5.5. Trips were hence snapped to the pertinent road arch. This operation allowed the selection of a subset of trips, i.e., those which originated/ended/transited within the university area during the morning and evening peak hours. As reported by Table 5.5, the selection amounted almost one out of three of the total number of trips. Such this share remarks a significant suggestion, i.e., Almabike vehicles were used even during non-working hours.

Total number of trips after database revision	213
Number of trips with origin, destination and/or in transit within the city centre, after database revision	186
Number of trips with origin, destination and/or in transit within the university area, during morning and evening peak hours, after database revision	69

Table 5.5. Main trips parameters and characteristics.

Chapter 6. Almabike results

6.1. Novelty

On the basis of literature overview illustrated in Chapter 1 and of the relevance of University Campuses impact in terms of urban sustainable mobility, as explained in Chapter 3, the present research has been focused on the findings about the specific category of University Student segment.
Following this purpose, it has been taken in account the case of University of Bologna, as huge university and characterized by a higher urban complexity and wide population of students, oriented in bike commuting. The main purpose of this research is to define a spotlight on the undiscovered category of University student cyclists.
In next paragraphs the relationship between environmental issues and university has been deepened and further the case study of University of Bologna has been explained. The scientific interest lies also on the framework of University of Bologna itself, whose complexity permits to create an overall perspective on this category.
Categorizing university students cyclists represents a novelty in scientific literature, in which the existing studies identified categories mainly on the habits and confidence with road infrastructures. But in literature it has been found a lack about the analysis on the specific university student category, that embraces a well-defined age range, a behavior bounded by academic activities and studies, and attitudes on city lifestyle and transportation patterns. This issue is more relevant within a urban context such as Bologna, a city that may be described as a traditional “University town based”, in which students represent approximately about 17% of entire resident population. The students residents distribution among territories generates urban patterns related to home-study commuting that offer a wide overview on cycle use and distribution in temporal and consistency terms. The main innovation and added value of the research is related to find indicators and parameters that may help to describe University students’ cyclists behavior and impact of urban structure on cycling, in terms of habits, speed and cycle-paths relevance on commuting. Information about student-cyclists can

be useful to target the enhancing of ecological mobility in university campuses, to analyze economic value shared by the student presence within hosting cities and to have a Decision-Support system with which improve the cycling infrastructures towards and near campuses. With respects to universities, they represent an ecosystem that can be external or fully integrated in an urban context. They attract several categories of people (students, professors and researchers, administrative staff, etc.) often covering long distances to reach different places in different hours of the day, thus requiring a sustainable planning approach.

Categorizing a cyclist's type means to identify specific items and requirements that describe deepening the choice made by this kind through several descriptors, i.e.: preference expressed on routing, frequency of bike usage, specific attitudes on travelling, road behavior, fears and attractions, distribution of cycling flow on time basis (per hours, per month/season), etc. Aspects that can be expressed in technical units as speed, km travelled, % of usage of cycle-path and others similar items.

6.2 Data configuration

After the activities illustrated in Chapter 5, the reviewed database was deeply analyzed in order to get information about University student-cyclists category, in terms mainly of users' choices and behaviors. The survey took place from the 15th February, 2021 till the 18th June, 2021. This period has been characterized by some peculiarities related to local policies for contrasting COVID-19 pandemic. In particular, these policies have been represented by specific movements restrictions and curfew, distal learning for university students and closures of commercial activities from 15th March to 11th April, 2021. Progressively, these limitations have been unleashed till June, 2021. In these terms, COVID-19 policies impacted on altering almost a month of usage of bicycle by students' category. Others factors has some effects on the survey. While the quantity of deployed bikes amounted 322 vehicles (189 distributed to male users and 133 distributed to female users), then have been reduced by 6 stolen bikes and by other 6 unusable vehicles due to irreparable GPS sensors, applied thresholds filtered 65 eligible cycles. The apparently low ratio between the deployed number of cycles and the amount of analyzable vehicles can be explained by the general framework of Almabike project (application for bike rentals were totally voluntary with no planned rewards for the virtuous riders) and the aforementioned legislation in terms of mobility during the survey period. The number of analyzable vehicles should hence be seen as a 'statistically-valid' subset of the entire set of bikes, while none of the bikes was totally inactive during the surveying period. Outcomes were assessed by authors as solid and meaningful, so analyses on both records (i.e., punctual actions) and movements (i.e., trips) were conducted. The following paragraphs trace the main results for the two focuses. In order to synthetize the main attributes used during the analysis, Table 6.1 shows most relevance basic parameters.

Road network length*	m	853,609
Road network length within the city center*	m	157,997
Reserved cycleway network length within Bologna Municipality*	m	225,151
Reserved cycleway network length within the city center*	m	39,491
Average trip length+	m	14,050
Share of trip in transit with origin, destination or in transit through the city center	%	59% (578)
Share of trip in transit at proximity to University zones**	%	33% (323)
Share of records within the city center	%	40% (10,469)
Share of records within a reserved cycleway, within Bologna Municipality	%	11% (2,729)
Share of records within a reserved cycleway, within the city center	%	16% (1,659)
Share of records within a reserved cycleway, within the city center, with respect of the total number of records within a reserved cycleway	%	60% (1,659)

Table 6.1. Main parameters (+: The set of value comprises only the filtered trips. *: This value was obtained from the ESRI Shapefile. **: A fixed-distance buffer area (100 m) was calculated).

While the original number of recorded points within the study area boundaries (i.e., Bologna city and the bordering municipalities) was 43,043, the total amount of analyzable data was 25,694 records (approximately 60% of the total). The chosen criterions for filtering points were restrictive time thresholds: eligible records should have had an associated time span between 30 and 60 seconds or equal to 0 seconds in case of starting point of a new journey. Most of the discarded records (i.e., points) had GPS errors, while the search in links outlayers detected un-predictable or unrealistic movements (i.e., those whose records were affected by coordinate biases). Due to the GPS average time interval in saving two subsequent records (60 seconds), assumptions on position jumps and related quality segments were not conducted. Figures 86 shows the spatial distribution of records in Bologna and surrounding municipalities, and Figures 6.1 and 6.2 indicate the relevant concentrations of trips close to university facilities.

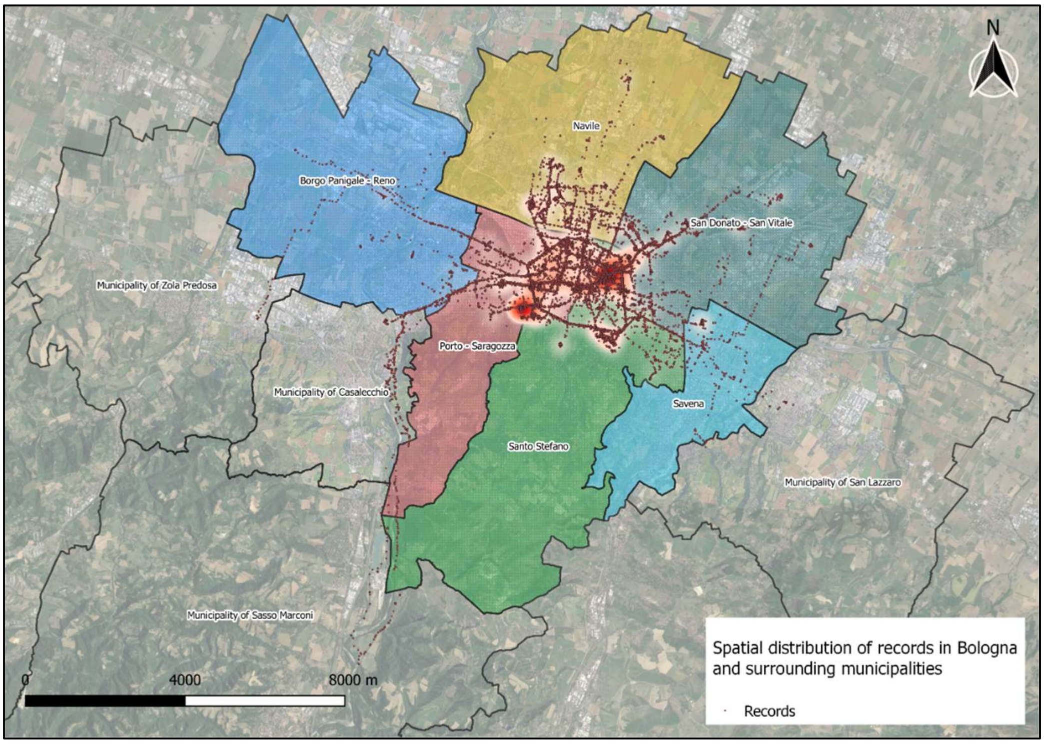


Figure 6.1. Spatial distribution of records (points and heatmap) in Bologna and surrounding municipalities.

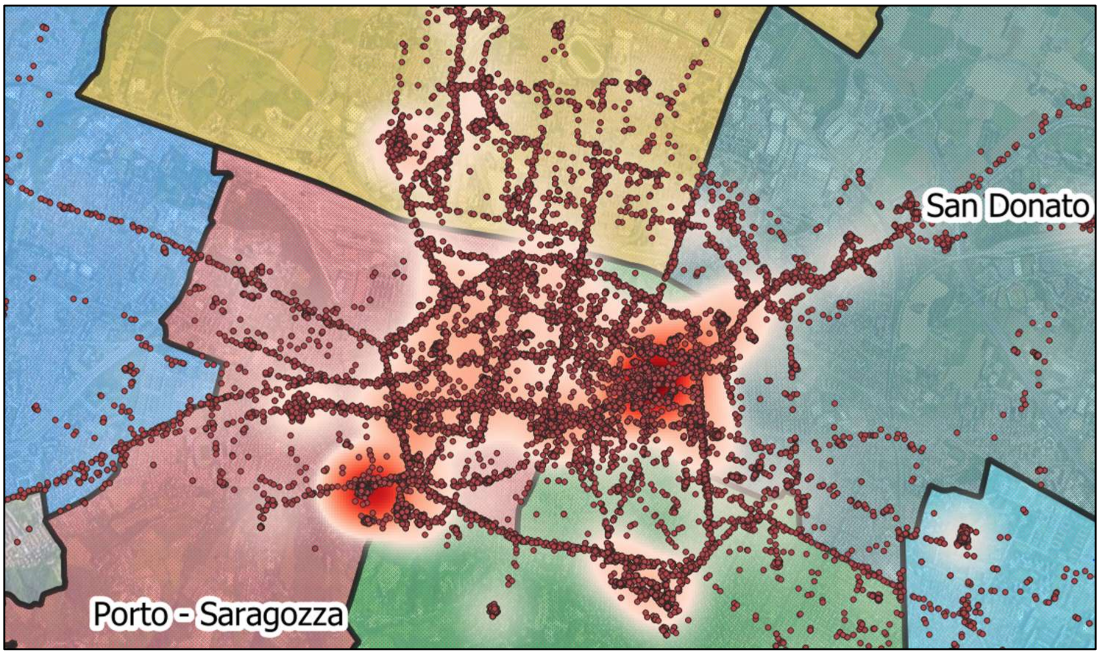


Figure 6.2. Spatial distribution. Detail on city centre.

From a general point of view, the aforementioned movement limitations affected the temporal distribution of travels. With respects to days of week, Wednesdays were the most-ridden days (6,627 records, 25,79% of the total). Considering the dates, the overall most-ridden days were Wednesday 24th February, 2021 (1,082 records), Sunday 25th April, 2021 (1,071 records) and Wednesday 19th May, 2021 (1,062 records). The two Wednesdays affect the global share, while Sunday 25th April is a civil holiday. According to the mobility patterns, records during the weekdays were registered mostly within the urban area, with a significant correlation between the records' location and the academic buildings, while records on Saturdays, Sundays and holidays were generally more dispersed and in proximity to leisure facilities. With regards to the time analysis, the only noteworthy correlations are the usages in early morning during weekdays (635 registered records between 7 AM and 9.30 AM, 570 of them between Monday and Friday) and during evenings in the spring months (6,807 registered records between 7 PM and 11:59 PM, 4,752 of them between late April and the end of the survey in June). Surprisingly, Saturday evenings counted only 282 records with well-defined patterns which don't embody any significant point of interest or leisure in the city center.

Nocturnal rides (i.e., records registered between 12 PM and 5 AM) amounted a very low share of registrations (112, 0.43% of the total) and were registered during the lighter limitation periods.

6.3 Analyses of Trips

Trips were created in QGis by applying to filtered database pertinent geoprocessing algorithms. Thanks to the attributes, and as well as records, trips' 'identity' (i.e., the vehicle, the day, the time) was always detectable. To improve a better representation of users' movements and to study their behaviors, records have been processed through two different approaches, so trips could be characterized by different attributes:

a) Trips extracted by "day" threshold: this procedure was conducted in order to focus on time distribution of trips. Links were properly aggregated with respect to date, so output vectors (i.e., movements sequence) were made up of the concatenation of subsequent records. This procedure, even if sufficiently detailed, is not time-sensitive, i.e., extended interval between two different trips cannot be detected. In fact, within the same day, users can ride more than once for different purposes (e.g., home-work/study trip, then work/study-leisure trip, then leisure-home trip). In order to deeper analyze the trips, time span was introduced as threshold.

b) Trips extracted by "day" and "timespan" thresholds: these two thresholds allowed a sort of "splitting" in trip sequence. This more detailed procedure was based on the previous assumptions, but it highlighted disconnected trips made for different purposes and, thanks to the associated attributes, it could be aggregated with respects to the date.

Every trip was created automatically by the algorithm from the processed database. Indeed, in order to strengthen the set of outputs, a manual check was conducted, so links valid by a statistical point of view but improvable were discarded. Even if this work has not focused on the relationships between urban form and travel, instantaneous speed was considered instead of average speed to reduce biases propagation. In fact, links were geometric (Euclidean) distances between the two pertinent reference points, so it minimized the links' non-sensitiveness of the "real" world (i.e., road structure, environmental characteristics, users' behavior, etc.), both in planar (i.e., the aforementioned discontinuities, the presence of turns, voluntary travel interruptions, etc.) and vertical profiles (i.e., slopes, terrain roughness, gradient, etc.). Figure 6.3 shows an overview of trip distribution. With respects to each bicycle, a preliminary analysis concerned the number of days with at least a record, the total number of registered records and the number of trips. On the basis that vehicles were recognizable by ad ID number, the three 'most active' bicycles were ID number 280, which summed 1,081 records and 79 trips in 33 days with an average speed = 7.65 kmph, ID number 278, which summed 830 records and 85 trips in 24 days with an average speed = 8.22 kmph and ID number 606, which summed 687 records and 51 trips in 12 days with an average speed = 9.51 kmph.

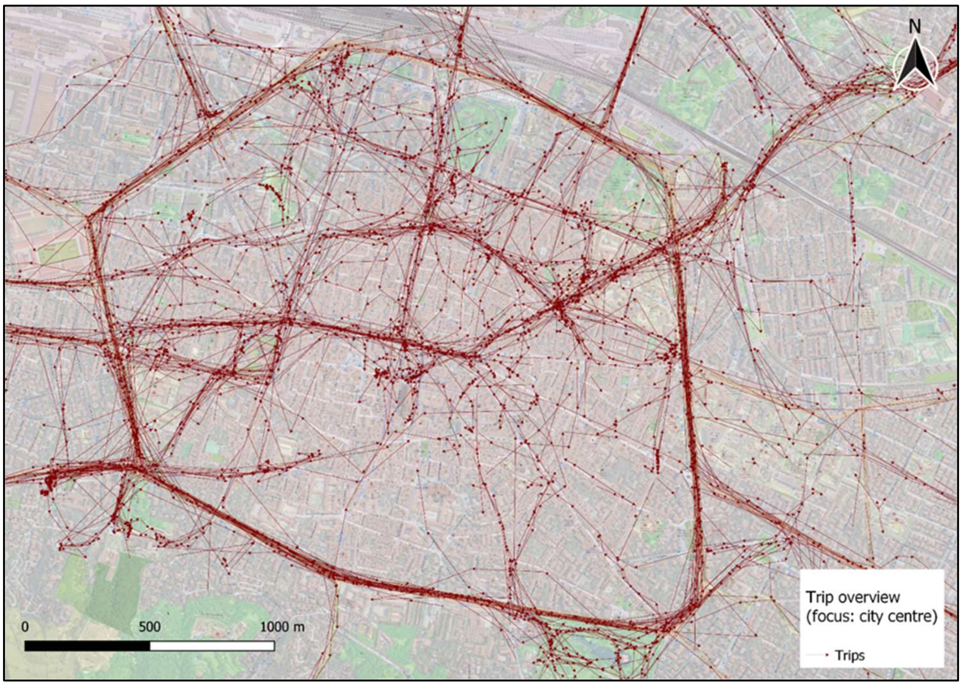


Figure 6.3. Trip distribution overview in city centre (applied threshold: "day" and "timespan").

Map matching procedures described in the previous chapter allowed detection of origin and destination of each trip. In order to have a meaningful and solid outcome, neighborhood subdivision for Bologna municipality was used as reference and, by using geoprocessing algorithms, it was attributed to records. Other type of spatial splitting (e.g., census areas) has not been used for technical reason regards territorial heterogeneous characteristics and excessive presence of wide space. On these bases, a neighborhood-based O/D matrix was traced. The analysis has been also extended to bordering Municipalities, such as Casalecchio di Reno, San Lazzaro di Savena, Sasso Marconi and Zola Predosa, strongly interested by Commuting movements to Bologna. Both internal (i.e., trips with origin and destination within the same area) and interzonal trips were considered. Figure 6.4 shows the O/D matrix flows filtered for trips within Bologna municipality; the size of the line corresponds to the trip number.

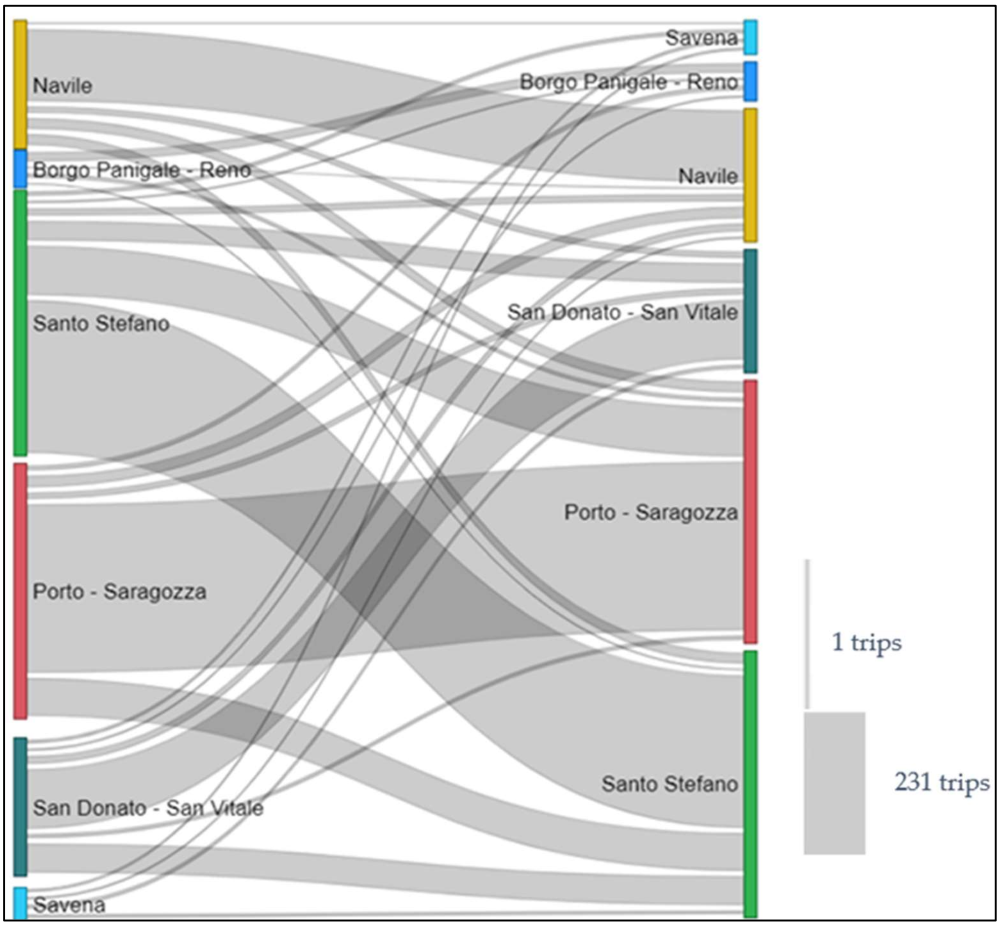


Figure 6.4. O/D matrix flows.

6.4 Analyses of bike-paths usage

Thanks to the coordinate translation, an overview of bike paths usage was observable. With this regard and with the aim of deepen the study of cycle-path usage, an overlapping analysis of records and trips to infrastructures was conducted in QGis. Shapefiles of records and trips were processed in order to detect how many points and trips involved a cycle-dedicated infrastructure and the percentage of involvement. The geometries, both points and lines, were associated to buffers of the specific subset of road network comprising those arches where the bike circulation is allowed. This kind of analysis was conducted thanks to specific attributes in road network database, freely available from the Open Data web portal of Bologna Municipality, which describes road typologies and roads where cycle circulation is allowed; moreover, by using the pertinent GIS algorithms, analyses on the presence of Almabike riders in the city center and the University zones could be traced.

The city center area comprises about 4.5 square kilometers of the oldest city (equal to 3.19% of municipality's surface), in which are located some of the main monuments and some University buildings, such as the "University Area" in Via Zamboni. With regards to the city center, a considerable share of 40% of analyzable records (equal to 10,469 points) were detected within the city center perimeter. Focusing on the trips, 146 started and ended within the city center, 399 originated from the city center (destination: internal or external the city center), 421 ended within the center (origin: internal or external the city center), while 430 didn't register any point within the city center. The global amount of the abovementioned trips isn't equal to the total number of studied trips (i.e., 969) because some of the trips (e.g., those with either origin or destination within the city center) could have been counted twice. With regards to the proximity to the University zones, 323 trips were detected within a distance of 100 meter from the main University buildings or facilities. They were detected by a fixed-distance buffer (100 meter) calculated by a QGis native algorithm. The distance was chosen in order to encompass both those riders who used to park their vehicles in the dedicated bike racks within the University areas and those who used to chain their bicycles far from the buildings. This phenomenon can be seen, for example, within the city center, where racks are quite spread and there is promiscuity in use (e.g., study, shopping, etc.). A deep analysis can be even traced for the bike-paths usage. As previously showed, data can be reported only as assumption because of the GPS errors and instrument limitations, which necessitated the aforementioned procedures and corrections in coordinates. Figure 6.5 shows those points assumed as part of a journey involving a bike path (green), in comparison with those assumed as recorded in a promiscuous road. Approximately 11% of them (2,729) were supposed to be recorded along a cycle-path, reserved cycleway or a road where cycle circulation is allowed (such as bike lanes), while Figure 6.6 shows the distribution of those sections of trips ridden at least 30% of their length along a cycle-path or a cycle-dedicated infrastructure. The red magnitude represents the percentage: the lighter red, the lower percentage, the darker red, the higher percentage. On the aforementioned basis (969 analyzable trips), 167 (17%) trips rode through a cycle-path for at least 20% of their length, 75 (8%) for at least 30% of their length, 39 (4%) for at least 40% of their length and 15 (1.5%) for at least 50% of their length. On the other hand, 216 (22%) never met a cycle-paths during the ride.

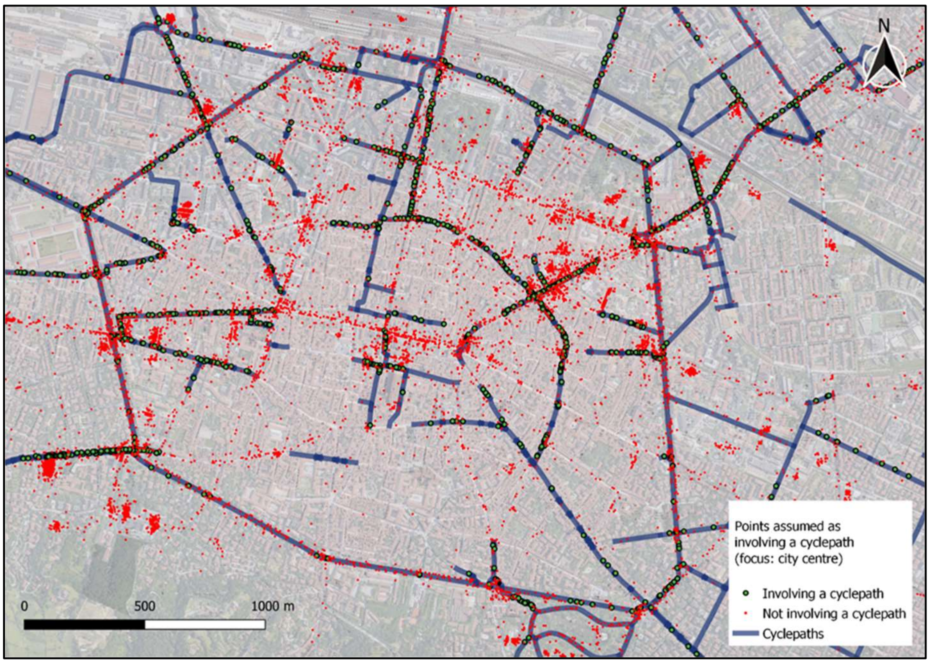


Figure 6.5. Cycle-path usage; records involving/not involving cycle-paths.

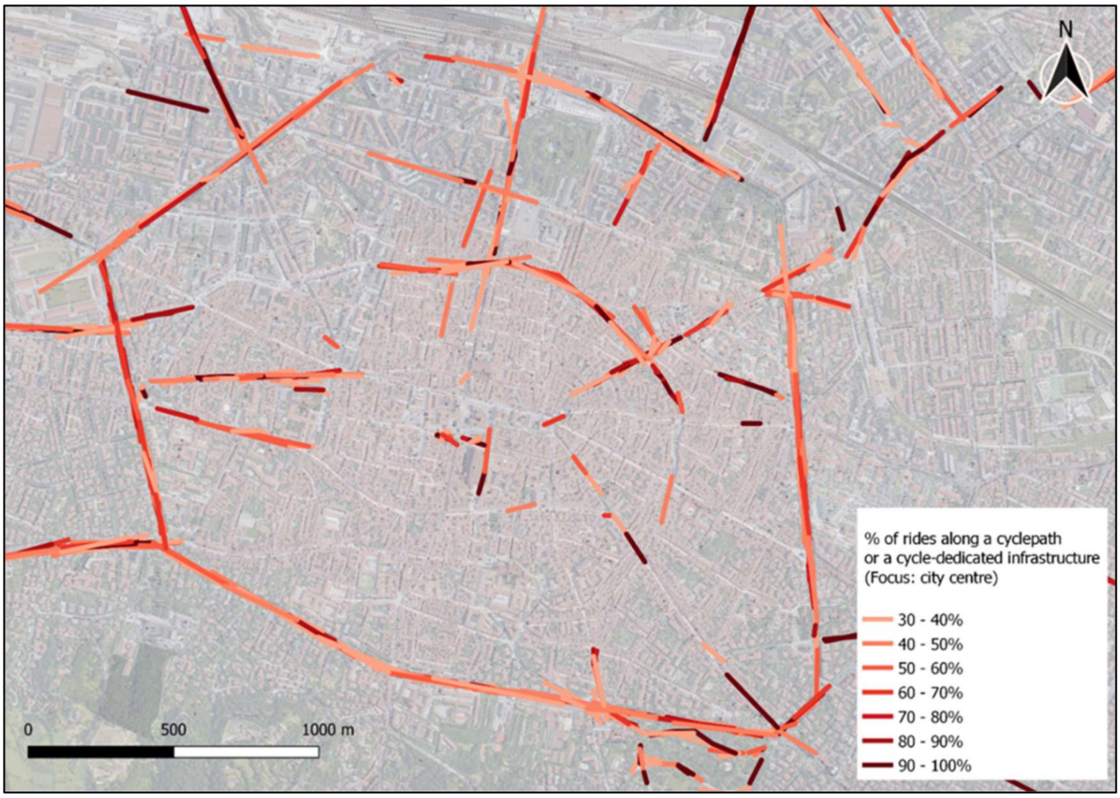


Figure 6.6. Distribution of sections of trips ridden at least 30% of their length along a cycle-dedicated infrastructure.

The distribution of flows during the period of observation per months and per hours, in terms of average flow, has been expressed in Figure 6.7, that helps to recognize traditional timing for students commuting home-campuses and periods of increasing use of bicycles.

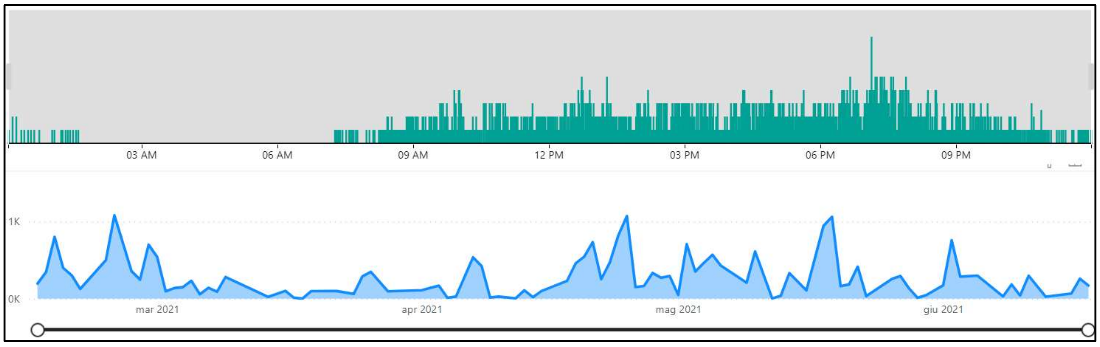


Figure 6.7. Distribution of trips per months and per hours (flow average value).

6.5 Feedbacks from riders: results from Almabike survey

As previously mentioned in Chapter 5, a survey has been submitted to users. Globally, 145 answers were submitted; with regards to the number of registered users, the rate of answer was 50,5%. As previously mentioned, even if only a subset of bikes has been analyzed, none of the bikes was totally inactive during the surveying period, so all the bikes' users could have been counted in the sample. It has been possible to have interesting findings about student perception on cycling. Considering the knowledge of the city ("Were you already confident with Bologna city (i.e.: were you able to orient yourself within urban structure?"), 90% of answers showed that user has been confidence with the urban configuration. Questions about behavior wanted to find some changes in mobility patterns before and after Almabike experimentation and COVID-19 pandemic. Before using Almabike, almost the totality of users used to get University by sustainable modes (144; 99%), while only a person drove car habitually. Consequently, Almabike seems to represents a consistent driver to change mobility behavior: only 13% of surveyed was a regular cyclist (19 answers; 17 were owner of a proprietary bicycle, while 2 of them moved from Mobike, the public bike sharing system, to Almabike), while 65 people (44%) were Public Transport users and 60 (41%) walkers. With regards to the impact of COVID-19 pandemic in mobility choices, a general and foreseeable reduction was visualizable from the answers. Seventy five responders stated they reduced their movements (51%), while 28 (19%) both reduced movements and changed their mean of transport towards more individual means. The reductions in movements were localizable in all the analyzed zones, both within Bologna Municipality and outside. With regards to Almabike usage, 109 people stated their mobility choices have been affected by Almabike. In particular, 46 of them reported a sensitive increasing of bicycle use; this is more evident in San Donato – San Vitale neighborhood, which totalized 12 answers (26%). With regards to the behavior while riding, a specific question was included in order to understand the usage of cycle paths. The 75% of answerers (110 out of 145) stated they used cycle infrastructures while riding, while 17% answered that they didn't use to ride on cycle-paths due to the absence of dedicated path on their habitual routes. The other answers stressed different aspects, such as the 'efficiency' of the network and its safety: only 4% showed that the reason for not use cycle-path was related to lower speed on cycle-paths than on traditional lanes. The answers about reasons of tripping have been confirmed by the prevalent use of Almabike: most of the riders used to mainly use this rented vehicle for personal daily needs (71, equal to 49%), while 64 (equal to 44%) for study reasons. Only 10 people (7%) used to ride for leisure or for weekend travels. This trend was coherent to the database analysis, which highlighted a comparably-low share of records during Saturdays, Sundays and during the evenings/nights. The aggregated analysis of the abovementioned answers shows that who used to ride Almabike for study and personal needs proportionally increased their bicycle use (in fact, despite a general reduction of the number of movements, 15 switched to individual transportation mean, 17%). According to the questions about users' satisfaction, 83 people rated Almabike with 4/5 or 5/5 points. The sample mean is 3.47/5, while the mode and median values are both 4.00/5. Considering the three monitored trip purposes, the rates were close similar: study-reasons users' evaluations totalized an average rate of 3.59/5, mode and median equal to 4.00/5; personal-needs users' evaluations totalized an average rate of 3.38/5, mode and median equal to 4.00/5; leisure-reasons users' evaluations totalized an average rate of 3.30/5, mode and median equal to 3.00/5.

6.6 Discussion

Globally, the average number of records per each bicycle is 165; they were registered in an average time interval of 5 days and they summed an average value of 15 trips, whose average speed is 7.36 kmph. This value is affected by traffic condition and it appears lower than previous analysis on cyclist (Poliziani et al., 2018) with respects to the average speed for urban cyclists. With respects to routes, the three longest journey presents 14 km, 13.52 km and 13.50 km respectively and they were registered by ID number: 606 on 20th April, 2021, with an average speed of 10.75 kmph; ID number:

223, 27th February, 2021, with an average speed of 4.49 kmph; ID number: 324, 17th June, 2021, with an average speed of 15.69 kmph. Globally, riders summed 1426 km (1.47 km averagely), with an average speed equal to 7.8 kmph. Even in this analysis, a remarkable correlation between time and space can be found: in the weekday time window 7 AM – 9.30 AM, 544 records were registered and some concentrations are localized close to academic buildings, denoting the use of Almabike to get the University.

After have filtered data, some considerations can be stated. Almost two third of the total amount of trips interested Santo Stefano and Porto – Saragozza neighborhoods, which comprise the city center, most of the university departments and, as consequence, it is conceivable that a conspicuous part of the students' residence is here. Peripherical neighborhoods (Savena and Borgo Panigale – Reno) were interested by a low number of trips, while Navile and San Donato – San Vitale amounted some records and trips due to the presence of other university facilities. From a general point of view, most of the trips were made within the same neighborhood, while the bordering municipalities accounted a very low share of events.

As the Figures 6.5 and 6.6 show, spatial distribution is not homogeneous: this is due to the dedicated infrastructure network and the traffic limitations, which are higher within the city center than the rest of the municipality. In fact, with regards to the share of records along dedicated infrastructures, 49% of them (1,352) are located within the city center. Focusing on the total number of points recorded along dedicated infrastructures and with regards to the location, the share is 13% of points recorded within the city center and 9% of points recorded outside the city center. These value shows the level of 'cyclability' within the central area. Thanks to the masked data of users' registry, a gender analysis can be conducted. Overall, Almabike vehicles were prevalently used by male users (18,926 records, equal to 74%). With regards to usage of dedicated infrastructures, the proportion is maintained: 73% of points (2,005 of 2,729) were recorded by male users. Detailing the share of records, no significant gender difference can be found: 10.53% of male-recorded points were along a dedicated infrastructure, while female share is equal to 11%.

As main remarks from the survey, the users' general evaluation about Almabike is positive. Rates and answers highlighted the utility of this kind of initiative, both as sustainable (and active) mean of transport for university population and as modal share 'diverter'. In fact, the above-seen trend (i.e., a slight but significant modal shift towards cycling) is particularly stressed by the answers of the survey. Almabike and the related survey was even a useful tool to detect some issues in cycle-dedicated infrastructures. In fact, even if the answers to the specifically-written question about the cycle-paths usage globally totalized only 10 responses, it was included in the survey in order to both compare declared behaviors with GPS data and to understand if something is lacking in the delivered policies. However, with regards to the comparison between registered data and survey answers, the usage of cycle-paths appears overestimated: while 76% of the answerers declared they used to ride along a dedicated infrastructure, only 11% of GPS records were associated to a cycle-path by the abovementioned procedures. This difference about users perception and practice behaviors has been explained on the basis of two converging factors: a) the fact that the movements have distribution almost entirely regarding city center in which, even if cycle-paths on reserved lane are not so common, the lanes are all subjected to 30kmph limits, and it is possible to find many pedestrian zone in which bicycles could ride in promiscuity with pedestrians; b) the fact that there is no exact correspondence between number of trips and 76% of users that have answered about use of dedicate lanes, because this 76% of users may have made less trips than the group that declare to prefer shared lanes.

The overall study has to be considered a valid instrument for the University student cyclists behavior evaluation. The main reason is that the existing restriction followed by COVID19 protocols has reduced the use of public transportation by student category and promoted an increased use of cycling. On that basis the findings on the University student-cyclists represents a significant sample, in which cycling should be more relevant than other years and consequently offered a wide overview on attitudes and characteristics. Further the research offers a methodology to investigate also urban point of interest for student and identifies urban spaces in which cycling infrastructures should be implemented to cover the spectrum of services and facilities for cyclists.

Chapter 7. Almabike research on environmental data awareness

7.1. Novelty

On the basis of literature overview illustrated in Chapters 1 and 3, in which it has been showed as academic and university staff after COVID-19 has demonstrated a relevant increase in individual mobility and specifically in cycling and walking, it has been focused the present research on finding some relationship between personal awareness of environmental data about lanes and the level on cycling for academic and administrative staff.

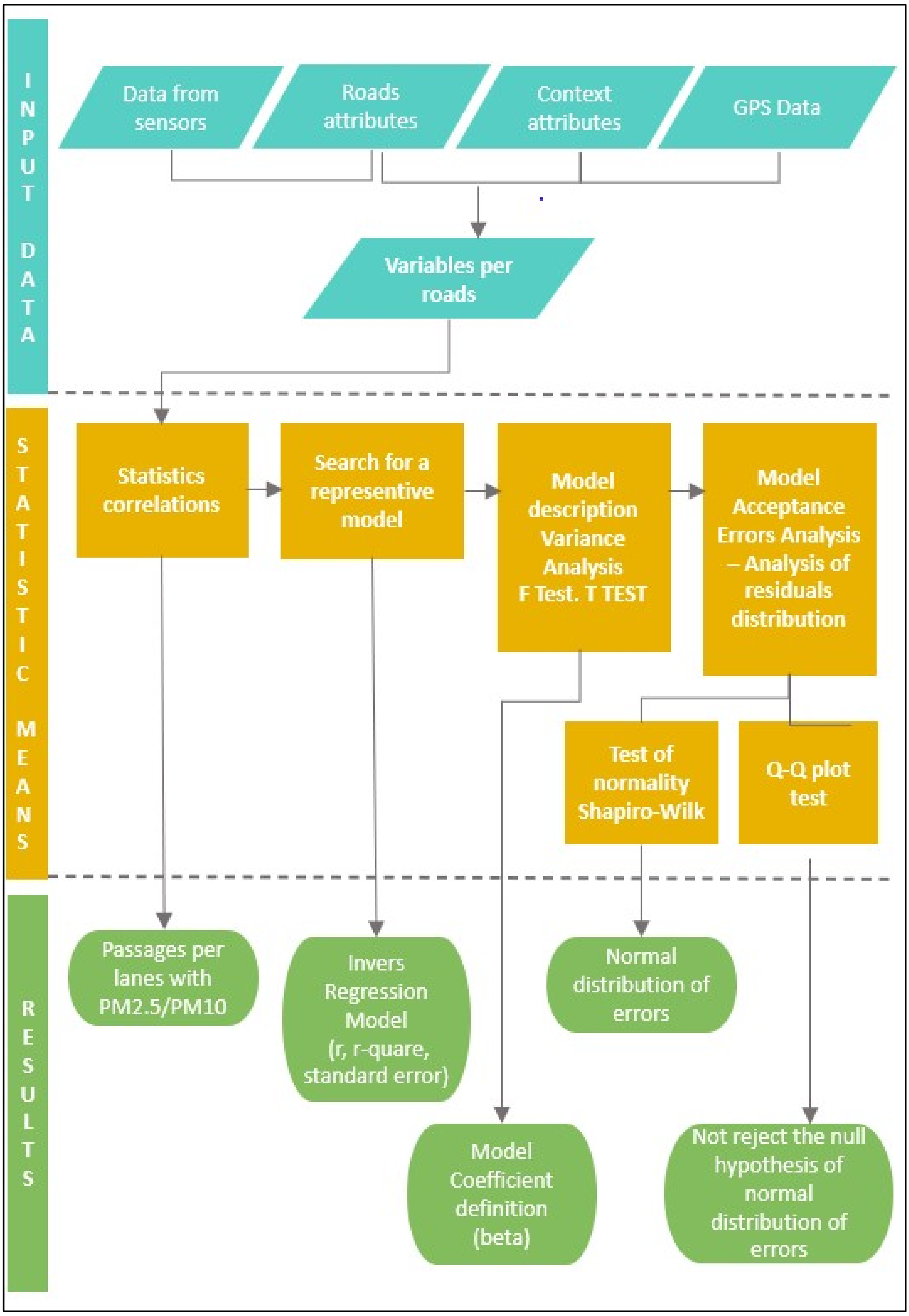
Indeed the main goal is to observe and find innovative items that may act on the increased cyclists category, to consolidate their interest in using bicycles as first mean, and to evaluate the relevant of being aware of pollutants could be a driven instrument to orient cycle-flow. In primis, that means investigates on realm of routing, then also search for further key elements to re-think the cycle-path design on the basis of recent approach, such as Healthy Street approach and Carlo Moreno's 15-minutes cities (Moreno et al., 2021), a concept that offers a novel perspective of chrono-urbanism in which most daily necessities can be accomplished by either walking or cycling from residents' homes.

The novelty of the research is based upon the lack found in literature of analysis concerning relationship between bicycles passages and environmental awareness of data by cyclist themselves. Further there are no studies about environmental data directly available and accessible for cyclists and also frequently environmental data are harvested by static station and not in dynamic. Consequently the analysis conducted present a multidisciplinary approach due to the fact that by a point of view the methodology enter into the field of social science and behavioral, by other point of view it is framed in infrastructural research by the fact that environmental data are connected with lanes also and permits finally to orient next researches on urbanism and connection between urban environment and healthy living.

In chapter 5 it has been described the data analysis and the database structure. In particular the relevant conceptual passages needed to obtain a database in which lanes should be associated with environmental parameters and passages of bicycles.

7.2 Results

In order to detect the exposure during the commuting time windows indicated in Chapter 5 paragraph 5.4, and thus to observe whether the environmental awareness of riders could be a factor in route choice or not, a statistic analysis has been conducted, as illustrated in Flow Chart 7.1. The aim has been to find correlations among variables and search for a statistic model. The analyses were performed using SPSS software, in which the analyzed variables has been: PM1; PM2.5; PM10; noise; cycle passages per road arch (i.e., 1=cycles are passed; 0=cycles are not passed); number of ridden trips on the selected road network (i.e., university area); proximity of road arch to green infrastructure, i.e., percentage of canopy coverage calculated as GIS geoprocessing output (i.e., overlay algorithm) between green infrastructure vector layer and road arch vector layer. The raw data has been treated as indicate in Chapter 5 and 6, in which the main steps before statistical analysis have been in order: environmental data related to passages have been associated all to any single road arch and then averaged in terms of pollutants value. The acceptability threshold on number of passage per road arch is 3. Each road arch with less than 3 passages has been avoided. Among all road arch it has been considered a limited zone most interested by University commuters movements, which boundaries are the main lane that surrounds university central neighborhood (via Zamboni, Irnerio, boulevard, and related axis). The road sample is homogeneus in terms of road characteristics and urban location. Less homogeneus in terms of traffic due to the fact that some lanes are in limited traffic zone and present a traffic reduction (I.e. Zamboni). The user sample is homogeneus in terms of academic components and home-work commuting attitudes.



Flow Chart 7.1

7.2.1 Correlations

Variables object of the Correlation analysis, aimed to find independence variable, have been settled among: particle matters per each lane, noise per each lane, environmental parameters (humidity and pressure) per each lane, existing cycle-path on each lane, bicycles passage per lane, proximity to relevant green infrastructures (i.e. boulevard with trees, parks, etc).

Correlation analysis output showed different results, as indicates in Table 7.1 and 7.2. Some significant correlations have been found and evaluated.

First, it has been possible to confirm the coherence of sensors detection performance on the basis that particle matters (PM1, PM2.5) present an inner relevant correlation at 0.01 level. This can be a second on-field confirmation, after test phase illustrated in chapter 5. PM1 and VOC have not been considered in statistical analysis for the reason that it has been evaluated impact of awareness on cycling only for particle matter with relevant public attention. Indeed there is a lack in normative and local policies on range level of health effect for PM1 and VOC. Given the purpose to evaluate effect of environmental awareness, based upon the most common public knowledge, it has been decide to avoid particles that have not public relevance and spread consciousness. Moreover at present, environmental legislation for air quality does not provide for a limit value for PM1 and the relevant bodies do not systematically monitor this air quality parameter.

Second a relevant correlation has been found among bicycles passages and particle matters. In particular the Pearson coefficient presents a negative value, demonstrating the level of correspondence existing between variables. Taking in account that it was mandatory for cyclists to observe pollutants distribution by lane and related value, this correlation can be interpreted as well as most polluted was a lane, as well as less cyclists were oriented to pass on it.

A relevant correlation has been established among bicycles passages and existing cycle-path, as to be expected, with Pearson coefficient positive.

Instead it has been not found relevant correlation among the following variables bicycles passages and proximity to green infrastructure, among particle matters and proximity to green infrastructures and neither bicycles passages and noise. Environmental parameters anyway are not considered as relevant for route choice.

Some hypothesis may be done especially concerning absence of correlation between bicycles passages and proximity to green infrastructure. Surely, since Kevin Lynch underlined in 1960 how amenities (personal or objective) may act on the choice of path during a trip, it should be simple to deduce a relationship between bicycles passages and proximity to green infrastructures and it should be easily demonstrating for leisure trips. But it also relevant to evaluate that it is commuter trip under analysis and there are more prevalent items able to orient the choose of path, i.e. time value, safety, moving freely than the perception of surrounding amenities.

Noise on contrary requires another consideration. Bologna, as easily detected even by the sensors, presented a high noise level, due to main factors: high level of traffic even in proximity to the very center and spread presence of traditional Bologna porticoes. These factors increased noise level and created an almost homogeneous condition among Bologna center. Consequently noise may be interpreted as a factor not impacting on route choice by cyclists.

No significance was observable also in the correlation analysis between the presence of cycling infrastructures and both particular matters and noise, due to the characteristic of urban center cycle-path, that basically are not isolated or separated by physical barriers (i.e. green barriers) from traffic.

		pm1	pm25	pm10	hum	press
PM1	Pearson Correlation	1	,928**	,929**	-,019	,319**
	Sig. (2-code)		,000	,000	,875	,008
	N	69	69	69	69	69
PM2.5	Pearson Correlation	,928**	1	,981**	,111	,274*
	Sig. (2-code)	,000		,000	,365	,023
	N	69	69	69	69	69
PM10	Pearson Correlation	,929**	,981**	1	,087	,268*
	Sig. (2-code)	,000	,000		,476	,026
	N	69	69	69	69	69
Hum	Pearson Correlation	-,019	,111	,087	1	,074
	Sig. (2-code)	,875	,365	,476		,544
	N	69	69	69	69	69
Press	Pearson Correlation	,319**	,274*	,268*	,074	1
	Sig. (2-code)	,008	,023	,026	,544	
	N	69	69	69	69	69
Noise	Pearson Correlation	,319**	,323**	,351**	-,056	,107
	Sig. (2-code)	,008	,007	,003	,649	,382
	N	69	69	69	69	69
Existing cycle-path	Pearson Correlation	-,070	,015	-,023	-,117	,082
	Sig. (2-code)	,566	,902	,851	,339	,500
	N	69	69	69	69	69
Bicycles passages	Pearson Correlation	-,502**	-,486**	-,507**	-,007	-,147
	Sig. (2-code)	,000	,000	,000	,955	,227
	N	69	69	69	69	69
Proximity to green infrastructures	Pearson Correlation	-,249*	-,228	-,203	,127	,184
	Sig. (2-code)	,039	,060	,094	,297	,131
	N	69	69	69	69	69

**. Correlation relevant at level 0,01 (2-code).

*. Correlation relevant at level 0,05 (2-code).

Table 7.1. Correlations.

		Noise	Existing cycle-path	Bicycles passages	Proximity to green infrastructures
PM1	Pearson Correlation	,319	-,070**	-,502**	-,249
	Sig. (2-code)	,008	,566	,000	,039
	N	69	69	69	69
PM2.5	Pearson Correlation	,323**	,015	-,486**	-,228
	Sig. (2-code)	,007	,902	,000	,060
	N	69	69	69	69
PM10	Pearson Correlation	,351**	-,023**	-,507	-,203
	Sig. (2-code)	,003	,851	,000	,094
	N	69	69	69	69
Hum	Pearson Correlation	-,056	-,117	-,007	,127
	Sig. (2-code)	,649	,339	,955	,297
	N	69	69	69	69
Press	Pearson Correlation	,107**	,082*	-,147*	,184
	Sig. (2-code)	,382	,500	,227	,131
	N	69	69	69	69
Noise	Pearson Correlation	1**	,005**	-,170**	-,184
	Sig. (2-code)		,968	,163	,131
	N	69	69	69	69
Existing cycle-path	Pearson Correlation	,005	1	,261	,109
	Sig. (2-code)	,968		,030	,374
	N	69	69	69	69
Bicycles passages	Pearson Correlation	-,170**	,261**	1**	,266
	Sig. (2-code)	,163	,030		,027
	N	69	69	69	69
Proximity to green infrastructures	Pearson Correlation	-,184*	,109	,266	1
	Sig. (2-code)	,131	,374	,027	
	N	69	69	69	69

**. Correlation relevant at level 0,01 (2-code).

*. Correlation relevant at level 0,05 (2-code).

Table 7.2. Correlations.

Given the relevance of the relationship between particle matters and bicycles passages the research has been focused on finding the descriptive regression model.

7.2.2 Regression models

The statistic model able to represent the correlations between particle matters and passages has been investigated through SPSS software and resulted the traditional polynomial model with exponent -1, renamed in SPSS as INVERS regression model.

The phenomena may be not described by a linear model due to the fact that in this case the intercept with the ordinate axis should represent a particle matter value as zero. This condition indeed is not adherent and consequently corresponding to realty, in which the urban context reports a constant presence of PM2.5 and PM10, even if with low level in some periods.

The INVERS regression model presents a high value of R^2.

The first correlation examined and its regression model are bicycles passages, overall 69, with PM 2.5 detected, as indicated in Table 7.3. The regression model has been synthesized in Table 7.4 and 7.5, where independent variable is PM2.5, which significance is demonstrated by R-square values.

		Variables	
		Dipendent	**Indipendent**
		PASSAGG	**PM 25**
Positive value number		69	69
Number of zero		0	0
Negative value number		0	0
Missing value numbers	**User-missing value**	0	0
	System missing value	0	0

Table 7.3. Variables processing synthesis. Bicycles passages with PM2.5.

R	R-square	R-square correct	Standard error of estimation
.853	.728	.724	4.780

Table 7.4. Regression model synthesis bicycles passages with PM2.5.

ANOVA[a]

	Sum square	df	Mean square	F	Sig.
Regression	4157.405	1	4157.405	181.967	.000
Residue	1553.595	68	22.847		
Total	5711.000	69			

Table 7.5. Regression test F. Bicycles passages with PM2.5.

Variance analysis presents a significant TEST F. Consequently it has been possible to define regression coefficients, as indicated in Table 7.6, in which it is possible to observe that the value derived by test “t” confirmed the significance of B coefficient.

	Non-standardized coefficients		standardized coefficients	t	Sig.
	B	Errore standard	Beta		
1 / PM 2.5	70.905	5.256	.853	13.490	.000

Table 7.6. Regression coefficient. Bicycles passages with PM2.5.

The regression model therefore is expressed by 1) and its trend in Figure 7.1.

1) $y = \frac{70,905}{x} + \mathcal{E}$

in which x is the PM.25, independent variable and Ɛ are the residues.

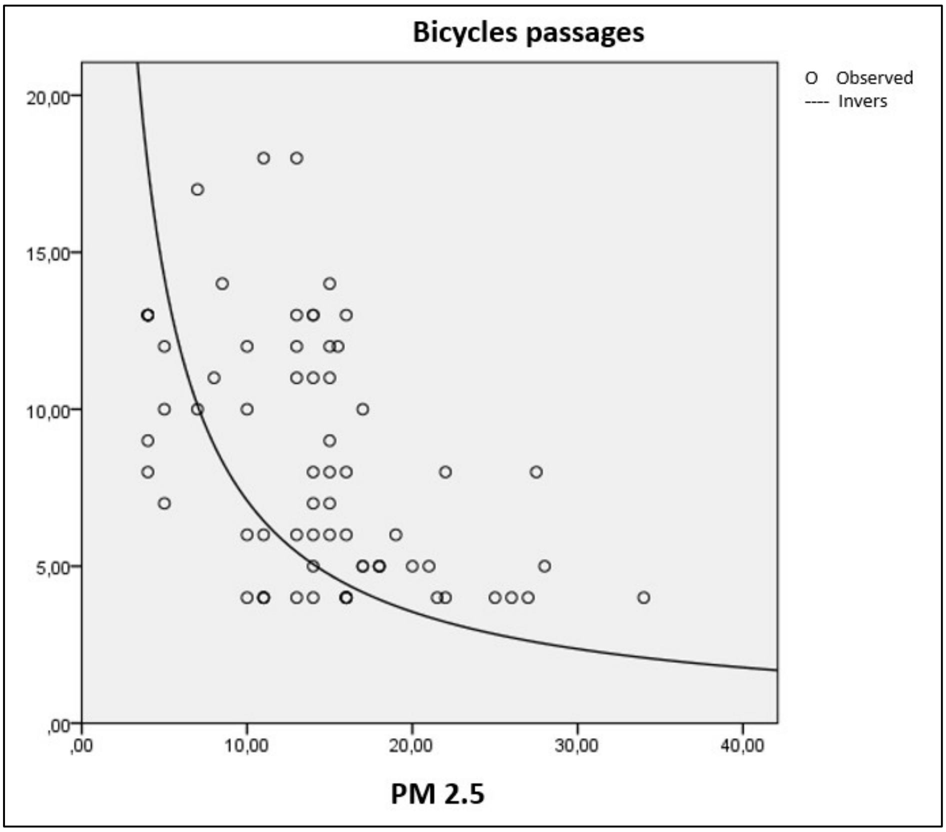


Figure 7.1. INVERS regression model trend. Bicycles passages with PM2.5.

It has followed the analysis of residues in order to confirm the overall acceptance of the model. In table 7.7 it has been indicated error descriptive parameters and in Figure 7.2 it has been showed histogram and Gaussian distribution.

N	**Valid**	69
	Missing	0
Mean		1.7102026
Median		1.2729948
Std deviation.		4.45860705
Range		22.27203
Minimum		-9.72627
Maximum		12.54576

Table 7.7. Descriptive residue parameters (errors on bicycles passages – PM 2.5).

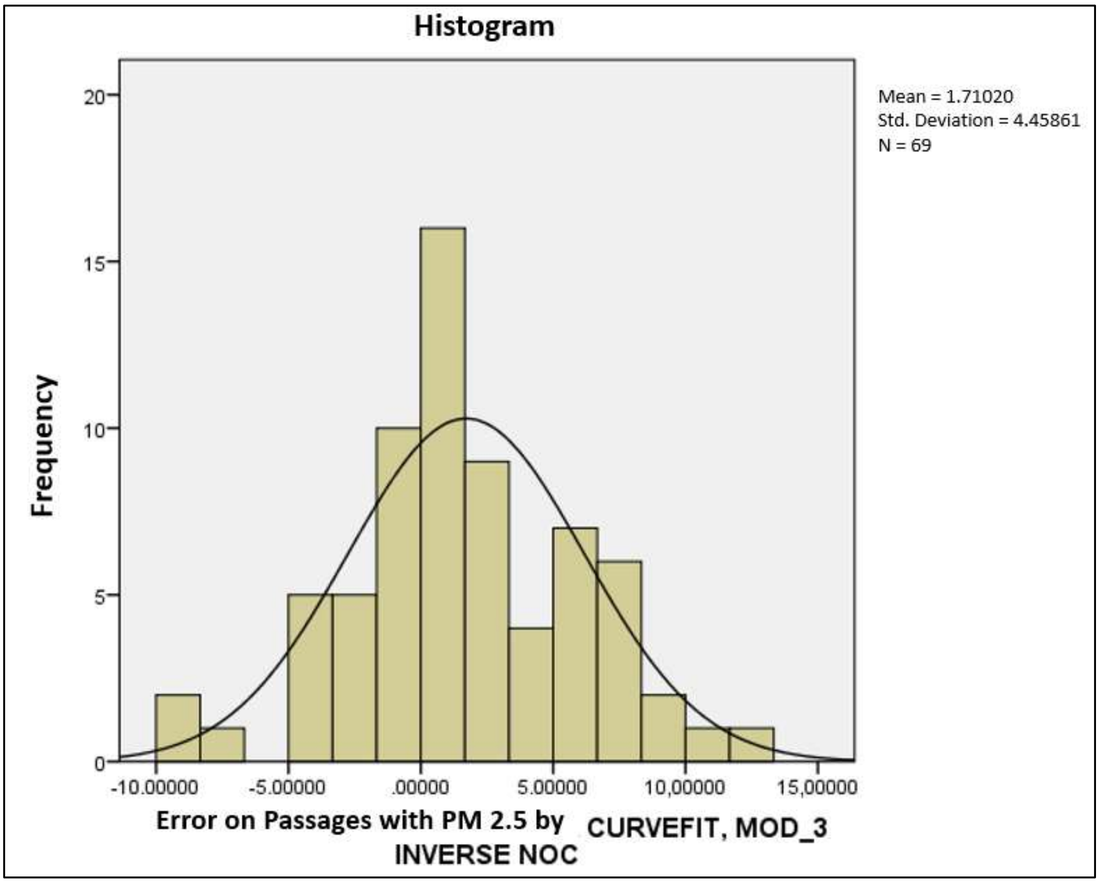


Figure 7.2. Residues Histogram and normal distribution. Bicycles passages with PM2.5.

On that basis to complete acceptability of residuals distribution it has been provided a Q-Q plot test. In figure 97 and Table 7.8 it has been showed how errors distribution is close to the straight line, confirming that it is a normal distribution.

	Cases				
	Valid		Missing		Total
	N	Percentage	N	Percentage	N
Errors on Bicycles passages with PM 2.5 by CURVEFIT, MOD_3 INVERSE NOC	69	100.0%	0	0.0%	69

Table 7.8. Errors on bicycles passages with PM 2.5.

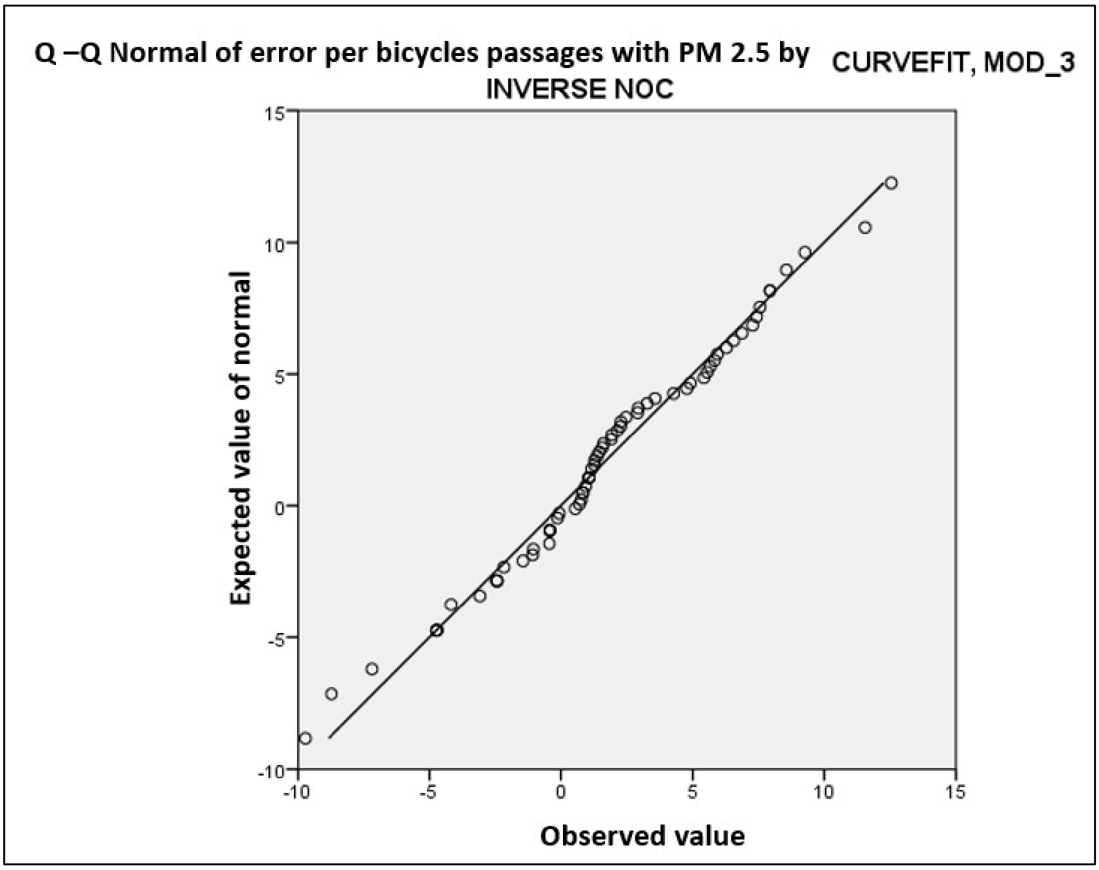


Figure 7.3. Q-Q plot normal of errors per bicycles passages with PM 2.5.

As illustrated in Table 7.9, to complete the residues analysis a Shapiro-Wilk test of normality has been applied, with the aim to do not reject the null hypothesis of normal distribution. In particular, a Kolmogorov-Smirnov test of normality it has not been applied due to the limited dimension of the champion (69 bicycles passage), in which cases it results a no valid test.

	Shapiro-Wilk		
	Statistic	df	Sig.
Error bicycles with PM2.5 da CURVEFIT, MOD_3 INVERSE NOC	,985	69	,568

Table 7.9. Shapiro-wilk test of normality. Residues of regression model of bicycles passages with PM2.5.

Concerning homoskedasticity, it has not been applied Levene test, that represents a deductive statistic used to evaluate the equality of variance for a variable calculated for two or more groups, due to the fact that the mentioned above test is basically structured upon a linear regression model and it is not represents a test fully suitable for the invers polynomial regression model.

Auto-correction of residues are not considered because it is not an analysis of historical series.

The second correlation examined is passages of bicycles with PM10, which variables as showed in Table 7.10. The methodology applied is the same of the previously showed, as illustrated in Table 7.11 and 7.12.

		Variables	
		Dipendent	**Indipendent**
		PASSAGG	**PM 10**
Positive value number		69	69
Number of zero		0	0
Negative value number		0	0
Missing value numbers	User-missing value	0	0
	System missing value	0	0

Table 7.10 Variables processing synthesis. Bicycles passages with PM10.

R	R-square	R-square correct	Standard error of estimation
.850	.722	.718	4.834

Table 7.11. Regression model synthesis. Bicycles passages with PM10.

ANOVA[a]

	Sum square	df	Mean square	F	Sig.
Regression	4122.216	1	4122.216	176.431	.000
Residue	1588.784	68	23.364		
Total	5711.000	69			

Table 7.12. Regression Test F. Bicycles passages with PM10.

Variance analysis presents a significant TEST F. Consequently it has been possible to define regression coefficients, as indicated in Table 7.13, and observe that value derived by test "t" confirmed the significance of B coefficient.

	Non-standardized coefficients		standardized coefficients	t	Sig.
	B	Errore standard	Beta		
1 / PM 10	73.277	5.517	.850	13.283	.000

Table 7.13. Regression coefficient. Bicycles passages with PM10.

The regression model therefore is expressed similarly to 1) and its trend in Figure 7.4.

2) $y = \frac{73.277}{q} + \mathcal{E}$

In which q is the PM 1, independent variable and Ɛ are the residues.

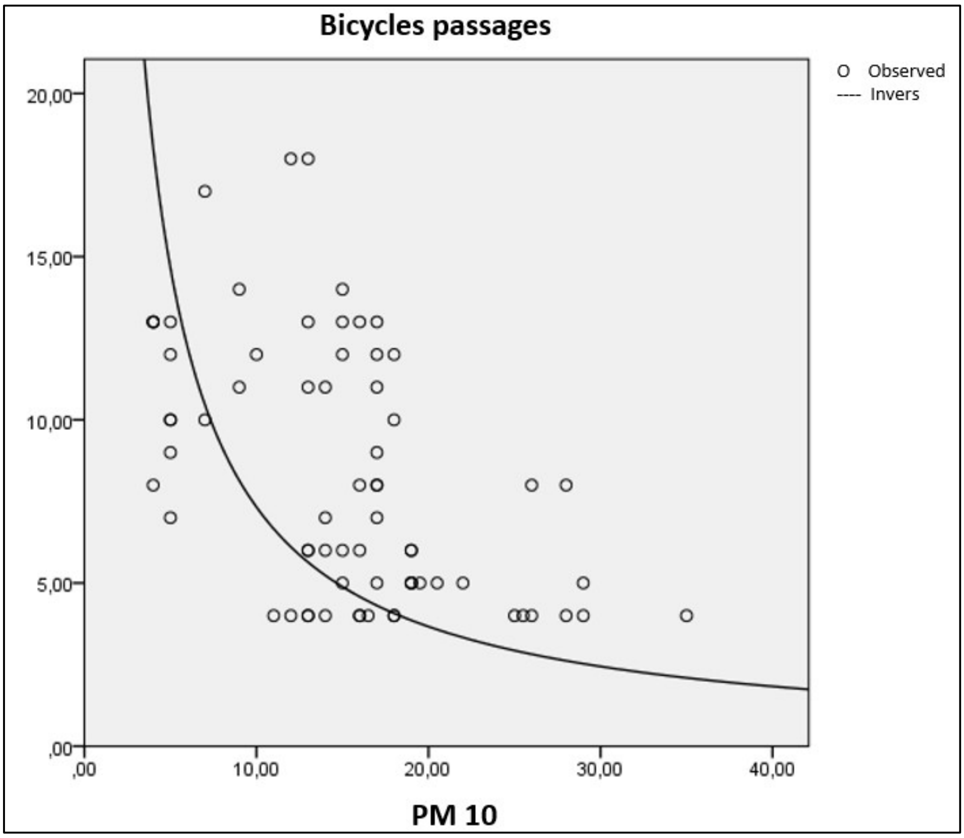


Figure 7.4. INVERS regression model trend. Bicycles passages with PM10.

As previously proceeded, the residues analysis has been conducted and results are synthetized in Table 7.14 and Figure 7.5.

N	Valid	69
	Missing	0
Mean		1.8213710
Median		1.8213710
Std deviation.		4.47194577
Range		22.68252
Minimum		-10.31920
Maximum		12.36332

Table 7.14. Descriptive residue parameters (errors on bicycles passages – PM 10).

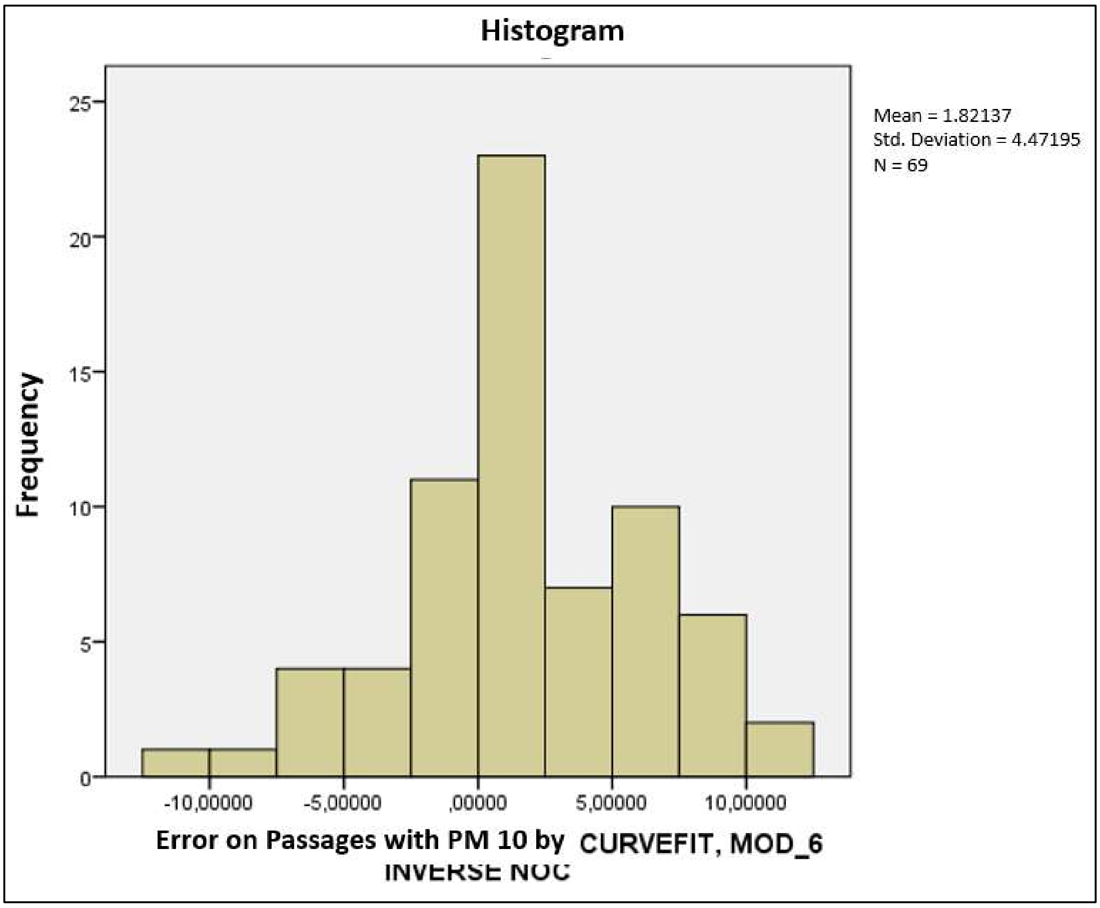


Figure 7.5. Residues Histogram and normal distribution. Bicycles passages with PM10.

On that basis to complete acceptability of residuals distribution it has been provided a Q-Q plot test. In figure 7.6 and Table 7.15 is showed how errors distribution is close to the straight line, confirming that it is a normal distribution.

	Cases				
	Valid		**Missing**		**Total**
	N	**Percentage**	**N**	**Percentage**	**N**
Errors on Bicycles passages with PM 10 by CURVEFIT, MOD_3 INVERSE NOC	69	100.0%	0	0.0%	69

Table 7.15 Errors on bicycles passages with PM 10.

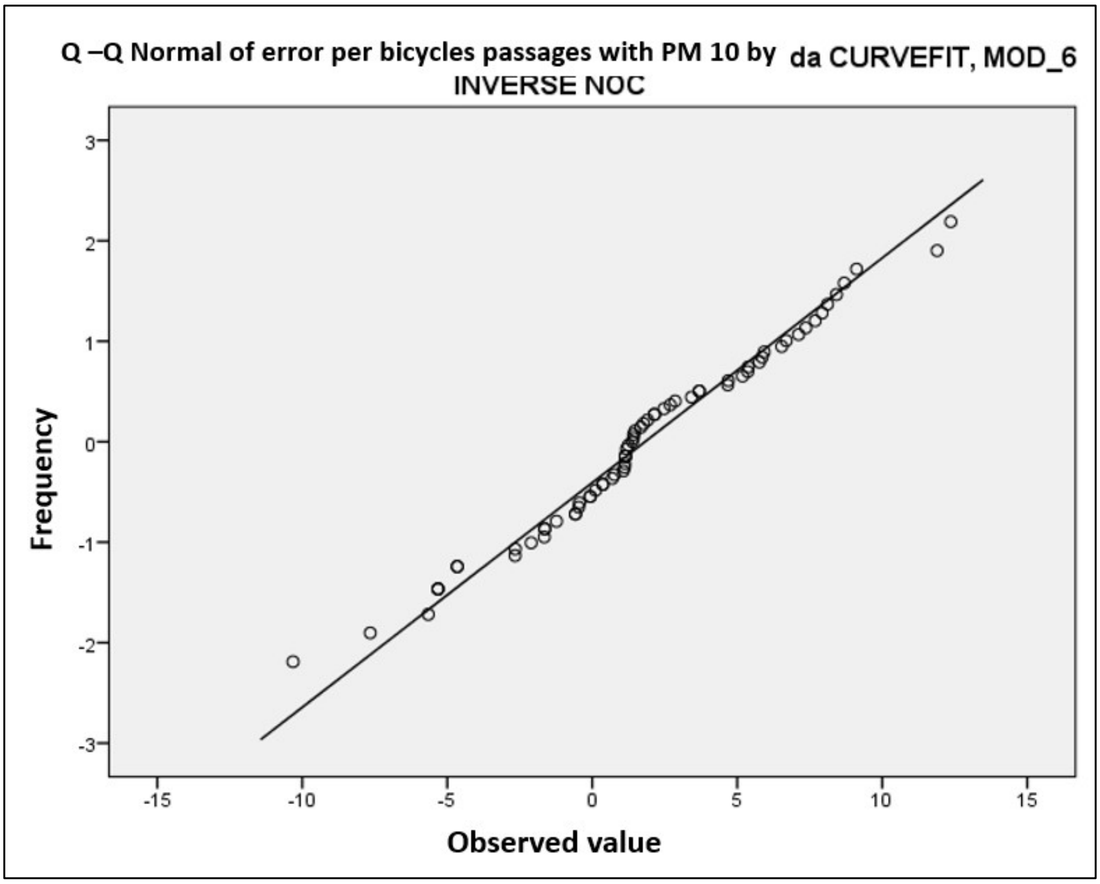


Figure 7.6. Q-Q plot normal of errors per bicycles passages with PM 10.

To complete the residues analysis a Shapiro-Wilk test of normality has been applied, with the aim to do not reject the null hypothesis of normal distribution, as illustrated in Table 7.16.

	Shapiro-Wilk		
	Statistica	df	Sig.
Errore per PASSAGG con pm25 da CURVEFIT, MOD_3 INVERSE NOC	.983	69	.491

Table 7.16. Shapiro-wilk test of normality. Residues of regression model of cycles passages with PM10.

7.2.3 Territorial environmental reporting

This part of the research exploits the environmental data harvested in the period of observation, with the aim to present an overview of level of pollutants per different urban spaces and several type of lanes. It has been take in account the same urban frame analysed in statistical analysis, as explained in Chapter 5.

In Figures 7.7 and 7.8 it has been displayed average PM 2.5 and PM 10 distribution on lanes in framed in urban sector analysed.

Figure 7.7. Average PM 2.5 associated with lanes.

Figure 7.8. Average PM 10 associated with lanes.

As indicated previously, noise requires a different approach. First, it has been demonstrated the absence of significant correlations between bicycles passages and noise level, and it has been explored the deductive reasons. Second, the fact that noise presents generally in Bologna a high average level means that it should be analysed in integrated terms, not only limited on congestion and traffic conditions. In Figure 7.9 it has been showed the average noise detected.

Figure 7.9. Noise associated with lanes.

The PM 1 distribution has been also investigated. The absence of regulations and policies makes this particle matter highly innovative. The distribution of PM1 has been explored in Figure 7.10.

Figure 7.10. PM 1 associated with lanes.

In figure 7.11 is represented the value fields for more relevant parameters, through a Boxplots.

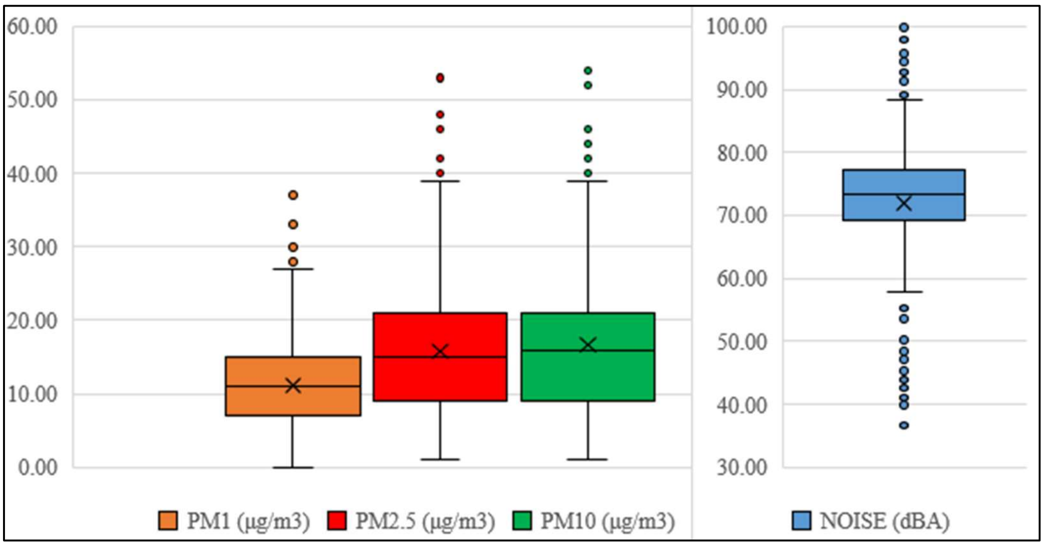


Figure 7.11. Boxplots of environmental variables.

The data has been compared with urban policy and urban structures and it has been possible to evaluate an early consideration about urban shape, infrastructures characteristics, urban policies and exposure determinants able to act on pollutants. In these terms in Table 7.17 it has been illustrated a first approach.

Pollutants	**Lanes with highest level**	**Lanes with lowest level**
PM 2.5	**Urban policies**: not traffic zone; parking lots accessible; presence of high attractive commercial activities.	**Urban policies**: total pedestrian zone, limited traffic zone in sub-order.
	Infrastructures: connection axis; lanes useful to reach parking area.	**Infrastructures:** cycle-path in separate lane; lanes entry to the very centre.
	Urban shape: lower distance among building;	**Urban shape**: green infrastructure presence;

	green spaces absence; parallel to hillside; tall buildings.	(trees platoons); greater distance among buildings; orientation from hillside to plainside; 2-3 floor buildings.
PM 10	**Urban policies**: as PM2.5.	**Urban policies**: as PM2.5.
	Infrastructures: as PM2.5.	**Infrastructures**: as PM2.5.
	Urban shape: as PM2.5.	**Urban shape**: as PM2.5.
Noise	**Urban policies:** open traffic lanes close to strong access limitation zones; higher presence of car parking lot on lanes.	**Urban policies:** pedestrian zones; wide spaces such as squares; absence of parking lots on lanes.
	Infrastructures: main connective axis; high presence of bus stop; high presence of crossroads.	**Infrastructures:** presence of shared cycle-path.
	Urban shape: absence of green, higher presence of bus stop, lower distance among buildings.	**Urban shape:** presence of green barriers or extensive green area; greater distance among buildings.
PM 1	Urban policies: as PM2.5.	Urban policies: as PM2.5.
	Infrastructures: as PM2.5.	Infrastructures: as PM2.5.
	Urban shape: as PM2.5.	Urban shape: as PM2.5.

Table 7.17. Early consideration and items concerning pollutant exposure and urban space.

In this very early approach some interesting consideration may be advanced. First, all particles matters have basically the same items. Second, it has been showed that compensative measure may reduce pollutant exposure. I.e. a traditional congested lane, as viale Berti Pichat, a part of the ring boulevard surrounding the very centre, presented abnormal values of particles, less intense than other lanes. The reason may be associated with the presence of a tree barriers that separate cycle-path with traffic lanes and the wide distance among facing building. Lanes orientation in function of hillside location may favour a change in particles distribution. Noise, that has a more homogeneous distribution, moreover offers interesting points: car accessibility, bus stop and frequency of car stop&go phases increase the level of noise, as well as high lower buildings or presence of wide public spaces (as square, large pedestrian streets, etc) decrease the level. PM1 seems to be less influenced than the others particles matter, presented a lower level distribution.

In general it has been considered how traditional urban policy oriented to reduce speed or access, permits to decrease in fact the level of pollutants. It is needed a specific attention on particle matters: some traffic lanes close to the total pedestrian or traffic limited zone, present a relevant increase of particles. That appears to be more sensitive on PM 1, than PM2.5 and PM10, in general more effected by even others items. Another interesting point is represented by the role of shared cycle-path. In Bologna, in particular in very narrow lanes in city centre, in which it is not possible to design a separated cycle lane, it has been signed on asphalt a dashed line. That line is mainly a sort of suggestion path for cyclists, but the relevance discovered in function of noise level seems to have also another role: to impact on speed reducing and traffic calming. Car drivers percept that this lane is shared and it is an uncommon situation that requires an highest level of attention, impacting on noise and also road safety.

7.3 Discussion

Although the sample of observations is limited in the overall number of passages (69), it was found in statistical terms that the more polluted a road is, the less passages of bicycles are recorded. This aspect, studied in this phase of research into correlations and related regression models, however induces an initial consideration regarding a behavioral aspect: the susceptibility of the cyclist's behavior with respect to his own ecological awareness. A first link in this sense could be advanced considering that cyclists have a more consolidated attitude to ecological behavior than other road users.

In other words, how an environmental warning can have an effect on one's behavior on the road. Consequently, it is possible to think about what effects should be obtained in sharing environmental information, according to a model as close as possible to real time. It is not difficult to imagine of a widespread information system capable of favouring less exposure of cyclists, with effects on health costs reduction and the general orientation of cyclists' routes on less polluted roads. But this aspect intersects with the elements of urban policies, infrastructural characteristics and urban form that act on pollutants, deduced from the survey. Consequently, orienting cyclists on less polluted roads involves identifying those roads characterized by parameters such as: fewer intersections, fewer bus stops, sites protected by green barriers, orthogonal orientation with respect to wind directions, etc.

This aspect applies to the built system but could also make a significant contribution to the new cycling infrastructures, whose structure, size and above all location context will have a role on the level of exposure of cyclists and their health conditions.

Some initial suggestions that the pollutants mapping has induced about cycle-path urban are:

- Extend traffic calming or speed reduction zones in urban area as possible.
- Establish routes that avoid high traffic exposure, narrow lanes and low high building zones.
- Where possible insert high tree barriers, in particular where traffic congestion presents frequent peaks (i.e. boulevard).
- Enhance shared cycle-path with dashed line on pavement, where lanes are narrow and relevant concentration of cars.
- Exploit pedestrian zone, squares and wide public spaces to establish nodes for cyclists, to decompress routes.
- Check wind orientation and urban path to define cycle routes that are able to run in same cycle-path direction (i.e. same urban canyon).

These initial considerations have to be deepened with further research on impact of pollution on road design and cycle routes, as illustrated in Chapter 8.

Chapter 8. Conclusions and further developments

8.1. Conclusions

Going back to the urban models of hybrid ecosystems, briefly explored in Chapter 1, in which digital and physical networks have generated new paths between ecosystem resources, the elements highlighted in this research show some significant aspects related: the role of the cycling infrastructure, the relevance of its position in the urban context, the influence of its spatial characteristics, as well as the indispensable presence of green barriers as environmental defence against particles presences. These first elements can act in the rebalancing of the flows that human presence has altered in urban contexts, as indicated in Chapter 1. However, that is possible if all aspects categorizing cyclists are well-known, as was outlined in the first part of the related research to university students. Knowing these attributes (speed, frequency of movement, distance covered in one's movement, the relationship between the location of the residence and the place of work/study, the propensity to use cycling infrastructure) allows the infrastructural elements to adapt at best to the aspects of demand. Here a relevant element is introduced: as can be deduced from the statistical effect between the level of pollution in the streets and the number of passages of bicycles, the behavioral cause-effect level is rapid and dynamic. This help to describe a new orientation of demand, understood here as an aspect acting on the choice of path, characterized by a changing and dynamic dimension. In order to achieve a static equilibrium that is no longer short-term as in traditional transport models, but very short-term just close to immediate, it is therefore necessary that the Transport offer should react equally in dynamic terms and capable of responding in the most adaptive ways.

From this consideration, therefore, it emerges that the two scientific fields of the Almabike project not only follow one another over time, but complement each other, offering both a scenario of subjective elements acting dynamically on demand and permitting also an early identification of design requirements, and urban and infrastructural, able to offer an adaptive response to the dynamism of the demand. To re-direct Cycle flows in real time in case that roads reach pollution peaks, requires a complex response that should be evaluated at a broader design level, i.e. by creating a network of alternative routes that can be activated in the same real time, whose standards of context and design allow a less exposure to cyclists.

This implication operates in the relevant transition from Urban Resilience (UR) to Urban Sustainability (US), as indicated in Chapter 1, introducing bottom up methods of participation based on the principles of citizen science. In these methodologies, people contribute to data collection and direct experimentation on the basis of their own behaviour, and helping to identify innovative aspects, both infrastructural and psychological, capable of being exploited to raise the cycling rate in medium-sized European cities. In fact, the Almabike project as a whole and holistic approach refers to an urban context of medium size (approximately 400,000 inhabitants) and to a complex university presence, articulated in a different territorial context, passing from partially self-sufficient peripheral campuses to contexts integrated into the fabric history of the city, similarly to other European cities.

The city-university relationship in this thesis is placed at the basis of the Almabike project itself. A relationship that frames a heterogeneous type of urban sub-system, with life dynamics very similar to the long-term tourism. As previously analysed, the creation of new social patterns and flows, produced by a huge university presence has been added to the economic advantages: places and spaces are created (residential system and production system) such as to redesign the city itself, modifying its shape and variables. Cycle mobility therefore becomes one of these variables, capable of redesigning the urban space, giving it a new function, in adherence to the Healthy Street model and capable of generating a positive change in the environmental dimensions of the city itself. Dimensions that consequently recall the European programs of Urban Health and wellbeing. These programs propose a new conceptual framework for considering the multi-factorial nature of both the determinants and the manifestations of health and wellbeing in urban populations.

The research object of this thesis has tried to maintain this multidisciplinary approach, generating a whole complex project, with a long development that has seen the following aspects of: planning, design, production of technological products and two distinct phases of experimentation.

However, the project can only represent a first step towards new areas that are only touched upon in the preliminary stage. In paragraph 8.2 the future developments of the research are analysed.

8.2 Researches next to be developed

Almabike project represents a first approach to the issues indicated in Chapter 1 and paragraph 8.1. There are different fields in which the research develop. Some are illustrated below:

- To extend in-deep analysis introduced in Chapter 7, defining an environmental urban model related to roads network. This research should be conducted first extending the observation period to winter/spring seasons, with the aim to complete the environmental data harvesting comparing seasonal effects on pollutants trends. The model requires a comparison with local environmental detection central, that operates by local governance to evaluate environmental parameters, and consequently orient the research through a different methodology aimed to cover more urban spaces. This may be done asking cyclist not to ride free, but sometimes to follow pre-defined path and tripping around stationary central detection, in order to compare data detected by sensors with data available through local open data. Second, it should be to create a complete roads classification on the basis of pollutants and to establish a decision support system, that based upon this classification, may orient infrastructural funding.

- To enhance data harvesting, introducing real time upload and accessibility by users. The current time gap between detection and visualization must be reduced in order to obtain a full chain between perception and reaction by cyclists. In these terms a dedicated app, available on smartphone, may permits deepened evaluation on cycling behaviour and may also use i.e. as data support for a Dynamic Cycling Model, in which local governance may favour to re-orient vehicles flows and cycling flow on the basis of the level of pollution.

- Development of specific transportation models, able to consider environmental awareness as a new variable oriented to assign cycling flows to the road network. In these terms during this work it has been established a scientific cooperation with Professor Shlomo Bekhor of Technion of Haifa, Israel, aimed to study the design of the that model, based upon Moshe ben Akiva's Logit model approach. The research has to be aimed to establish the weight of be given to the items "environmental awareness", among others variables as: shortest distance, number of intersections, presence of cycle-paths and their type, presence of relevant amenities along the path, etc.

- To evaluate health condition of urban cyclists, it should be interested to cross environmental data harvesting with tear sampling. Indeed tears represent a valid organic repository for pollutants and external environmental factors. With the comparison between particle matters detected by sensors and particles present in tears it should be possible to evaluate first how many pollutants enter in contact with physical body and any possible damage to retina surface. Once the quantity of the pollutant has been established, it is necessary to verify which places in the urban space have actually generated the greatest exposure and effect on health. Consequently, through the help of geo-positioning, it is necessary to identify which infrastructural and urban attributes have the spaces with the greatest impact on the body and finally to establish design characteristics to improve the places crossed by cyclists. Finally a survey may be submitted to users to add information about health condition of cyclists to cross with quantities of pollutants. Currently this research is in an on-going phase, through a cooperation established among DICAM and DIMEC – Department of Medicine and Surgical Sciences.

These different approaches are currently in course of development and may represent the next frontier of the research. Moreover it has been considered as relevant to scale this project in European cities of middle size structure and with the presence of university to claim a wide overview on the phenomena of university cycling and the impact of this factor in Sustainable Urban Plan. An initial investigation on similar European cities has found the following context possibly appropriate for scaling and exporting the project, defined by similar range of population and university presence with high number of students in a middle-sized cities: Copenhagen, Hagen, Lyon and secondary Zaragoza and Tel Aviv (Extra UE).

During the exploitation and scaling it should be part of the study to analyse urban morphology, finding the level of urban sprawl and conurbation process may be in act, to evaluate housing and transportation policies as well as road network development.

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